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Behavior of Stratified Undrained Contractive Silty Sands Under Seismic Liquefaction Conditions

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12 b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

Many failures of high hazard dams, earth structures, slopes, and foundations have been attributed to the liquefaction of saturated soils. The cyclic behavior of stratified silty sandy soils is presently poorly understood, yet these materials are commonly found in alluvial deposits and hydraulic fills, which have a history of liquefaction during earthquakes. The main objective of the research project was to compare the behavior of stratified and homogeneous silty sands during seismic liquefaction conditions for various silt contents and confining pressures. A

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comprehensive experimental program was undertaken in which a total of hundred fifty stress-controlled cyclic triaxial tests were performed. Two methods of sample preparation were used for each soil type. These methods included moist tamping (representing uniform soil conditions) and sedimentation (representing layered soil conditions). The silt contents ranged from 10 to 50 percent, and confining pressures in the range of 50 KPa to 250 KPa were considered. The following primary conclusions were obtained as a result of this study.

1. The liquefaction resistance of layered and uniform soils are not significantly different, despite the fact that the sand fabric produced by the two methods of sample preparation is totally different. This behavior was observed for both isotropically and anisotropically consolidated specimens and under a wide range of silt contents and confining pressures. This finding justifies applying the laboratory tests results to the field conditions for the range of variable studied.

2. As the confining pressure increased, the liquefaction resistance of silty sands decreased for both layered and uniform soil conditions.

3. The increase in silt content (percent passing No. 200 sieve) causes the liquefaction resistance of silty sands to increase for both uniform and layered soil conditions.

4. As the value of anisotropic stress ratio, K_c increased, the number of cycles to liquefaction also increased for a given stress ratio for both uniform and layered soil conditions.

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APPENDICES

BEHAVIOR OF STRATIFIED UNDRAINED CONTRACTIVE SILTY SANDS UNDER SEISMIC LIQUEFACTION CONDITIONS

1. INTRODUCTION

During an earthquake, cyclic shear stresses in a deposit of saturated loose sand cause a progressive build-up of pore-water pressure. When this pore-water pressure reaches a value equal to the initial confining pressure, the soil does not possess any strength, and it develops into a liquified state. State-of-the-art reviews of seismic liquefaction of soils have been presented in several references including Gu, et al. (1993), Castro et al. (1992), Ishihara et al. (1991) and National Research Council (1985).

Most previous research on liquefaction have been focused on uniform clean sands or gravel, containing little or no fines. A number of case histories have indicated that soils other than uniform clean sands can also liquefy (e.g., Dobry and Alvarez, 1967; Kuribayashi and Tatsuoka, 1975; Seed et al., 1983; and Wei, et al., 1981). In these studies, the soils which liquefied contained varying amounts of fine material. In addition, the seismic liquefaction of sand-silt mixtures have been systematically investigated in several studies including Dobry et al., 1967, Marcuson and Gilbert (1972), Ishihara et al. (1981), and Clukey, et al. (1980). Observations during the 1976 Tangshan, China earthquake indicated that some fine grained soils had also liquefied (e.g., Chang, 1987).

To date, a comprehensive understanding of the liquefaction behavior of stratified undrained silty sandy soils under seismic liquefaction, that can take into account the effect of soil type, is lacking. In this study, the behavior of such soils was systematically investigated

considering the effect of soil type and gradation as well as effective confining pressure. Stratified silty sandy soils exist in the field where various soil types have been deposited through water by nature (alluvial, lacustrine, marine deposits) or by man (hydraulic fills). It is known from past observations during earthquakes that these types of soil deposits often experience liquefaction.

2. STATEMENT OF THE PROBLEM

2.1 Background

Almost all laboratory seismic liquefaction studies have dealt with homogeneous soil conditions only, although stratified fine soils exist for various soil deposits. A limited study of behavior of layered silty sands was performed by Dobry and his coworkers (Vasquez-Herrera and Dobry, 1989). After examination of the results for two different sample preparation methods, namely moist tamping (representing homogeneous soil conditions) and sedimentation (representing stratified soil conditions), they concluded that the behavior of layered and homogeneous soils are not significantly different in terms of the triggering relationships, despite the fact the sand fabric produced by these two methods was totally different. This observation has been summarized by Marcuson, Hynes, and Franklin of U.S. Army Waterways Experiment Station (Marcuson, et al., 1990).

In addition, the behavior of layered sand-silt soils have been recently studied using centrifuge model tests (Fiegel and Kutter, 1992) through research projects sponsored by National Science Foundation and the Naval Civil Engineering Laboratory. The layered soil model consisted of fine sand and was overlain by a relatively impermeable silt. Pore-water pressures, accelerations, and settlements were measured during the tests. Results from the model tests

involving layered soils suggested that during liquefaction a water interlayere or very loose zone of soil may develop at the sand-silt interface due to the difference in permeabilities. In the layered tests, boils were observed on the surface of silt layer. These boils were concentrated in the thinnest zones of the overlaying silt layer and provided a vent for the excess pore-water pressure generated in the fine sand. No liquefaction flow failure was noted during centrifuge tests studies.

2.2 Objectives of the Proposed Study

The primary objective of this study was to compare the behavior of stratified and homogeneous silty sands during seismic liquefaction for various soil types and gradation. The study also investigated the behavior of layered soils over a range of confining pressures typical of field conditions. In addition, the effect of anisotropically consolidated soil conditions on liquefaction behavior of layered soils was investigated. The study provided a comprehensive behavior of stratified silty sands during seismic liquefaction conditions.

3. EXPERIMENTAL PROCEDURES

3.1 Soils Tested

To accomplish the objectives of this study, soils with varying fines content (percent passing No. 200 sieve) were used. The fines content ranged from 0 to 50 percent. The soils properties for the soils used during this study are shown in Table 1. The silty sandy soils were prepared by mixing appropriate amounts of Ottawa 20-30 sands with low plasticity silt. The silts had a liquid limit of approximately 20, and a plasticity index of about 8. The grain size distribution curves for the soils are shown in Figure 1. The void ratios ranged from 0.62 to 0.75 and the target relative density was 40%.

Table 1. Properties of Soils Tested

Series	Fine Content	G_s	D_{50} (mm)	C_u	Particle Shape
A	0	2.64	0.69	1.0	Rounded
B	10	2.64	0.67	7.5	Subrounded to Subangular
C	30	2.65	0.66	93.0	Subrounded to Subangular
D	40	2.66	0.65	136.0	Subrounded to Subangular
E	50	2.68	0.25	200.0	Subrounded to Subangular

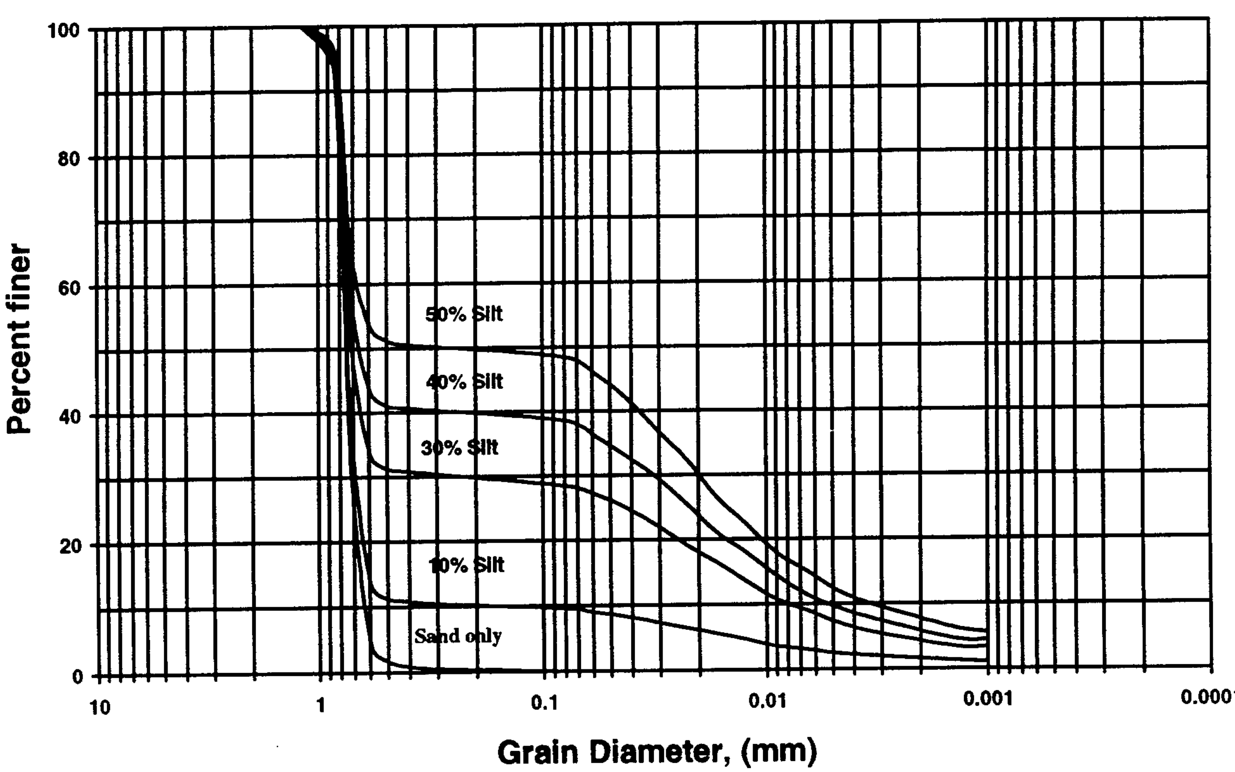

Figure 1. Grain Size Distribution Curves for Soils Tested

3.2 Equipment

For the purpose of performing the stress-controlled cyclic triaxial tests, the Automated Triaxial Testing System, developed by C. K. Chan, was used (Li, et al., 1988). A schematic of the Automated Triaxial Testing System at the University of the District of Columbia is shown in Figure 2, and a photograph of a soil sample after liquefaction is shown in Figure 3. This system is capable of performing both static and dynamic testing. In the automated system the computer programmed electronic signals for frequency and magnitude of loading are applied to an electro-pneumatic transducer that then controls pneumatic amplifiers for the application loading. Two control channels allow the independent and synchronized adjustment of the axial load and chamber pressure. The computer controls the whole system, receiving and storing the real time data in its memory and issuing control signals to conduct the required tests. The software includes a number of applications, namely back pressure saturation, consolidation, shear loading, and cyclic loading, amongst others.

3.3 Methods of Sample Preparation

Two methods of sample preparation were utilized for each soil type. These methods include moist tamping (representing homogeneous soil conditions) and the wet pluviation (representing layered soil conditions). The methods are described below.

The first method was the moist tamping using an undercompaction procedure (Ladd, 1977; Ladd 1978) which simulated a homogeneous soil condition. The procedure incorporated a tamping method of compacting moist soils in layers. Each successive layer was compacted to an increased percentage of the required unit weight of the specimens. The procedure consisted of pouring increasing amounts of soils (by weight) for constant height successive layers. Using this method, the compaction of each succeeding layer could further densify the sand below it,

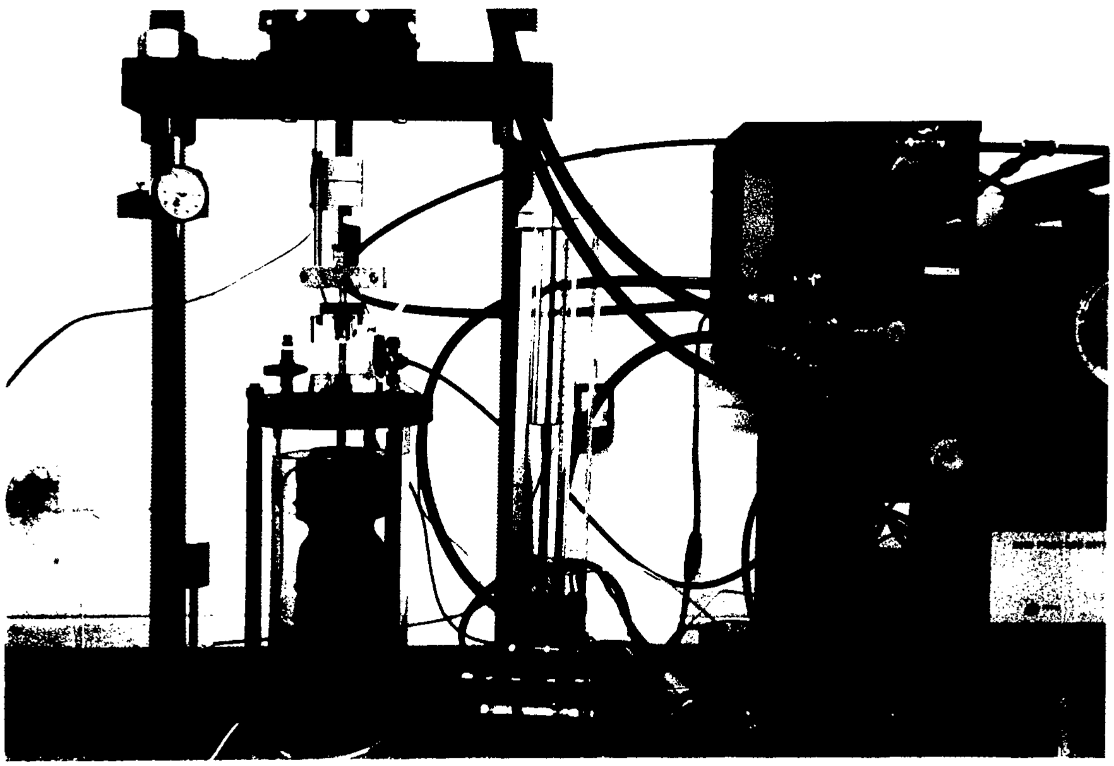

Figure 2. Schematic of the Automated Triaxial Testing System at the University of the District of Columbia

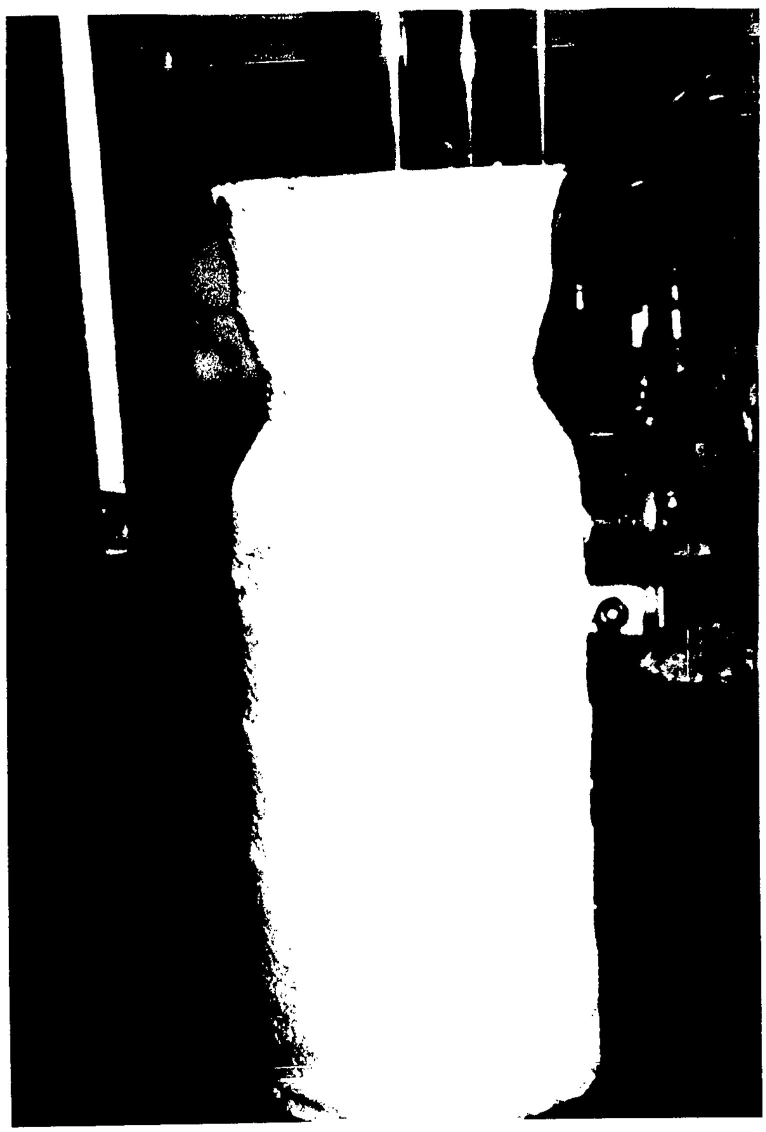

Figure 3. Photograph of Soil Specimen After Liquefaction

and therefore a uniform specimen was obtained. To avoid densification, water was added to give the sample strength through capillary stresses. The soil mixtures were usually poured in layers and tamped using specified weights. Details of this method can be found in several references including Ladd, 1977, Ladd, 1982, and Vasquez-Herrera and Dobry, 1989.

The second method involved the use of wet pluviation (sedimentation) procedure to simulate layered soil conditions. Using this method, the mold with a stretched membrane was filled with deaired water. Soil layers (typically seven layers) were then constructed by pouring equal weights of soil and waiting for at least one hour for sedimentation. Because of the different settling rates of coarse and fine grains, the most coarse-grained portion settles at the bottom and grades to fines at the top within each layer. Specimens with varying void ratios could be prepared by this method.

3.4 Variables Studied

The main variable for the purpose of comparing behavior of uniform and layered soil is the silt content. The silt content ranged from 0 to 50 percent. Another important variable was the effective confining pressure. Confining pressures in the range of 50 KPa (7.25 psi) to 250 KPa (36.25 psi) were used. The value of K_c (ratio of major to minor principal effective stress at the end of consolidation) ranged from 1.0 to 2.0

4. RESULTS

4.1 Effect of Silt Content

The effect of silt content on the liquefaction behavior is shown in Figures 4 and 5. The liquefaction resistance of silty sands generally increased with increasing silt content for both uniform and layered soils conditions.

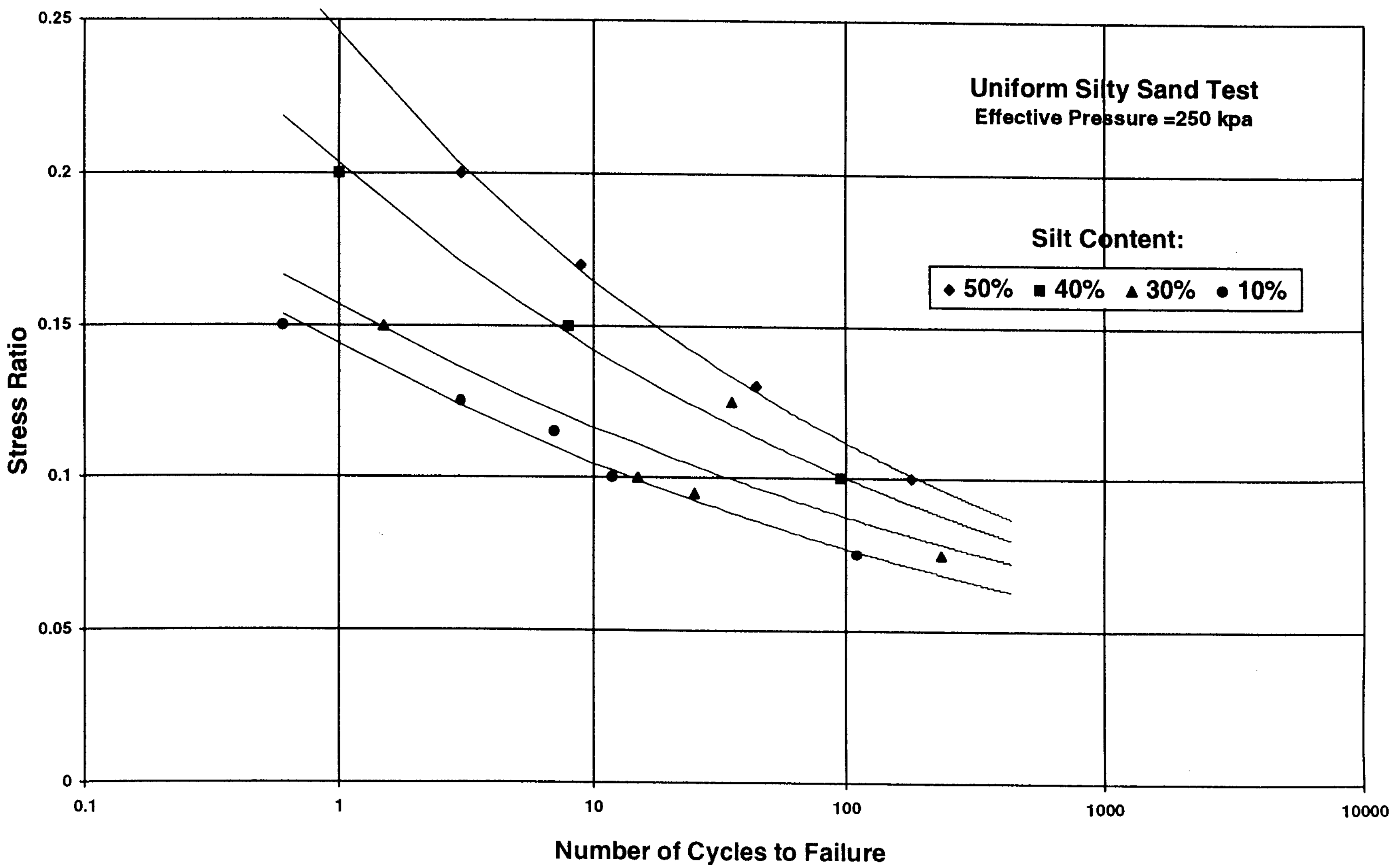

Figure 4. Effect of Silt Content on the Liquefaction of Uniform Silty Sands, $D_r = 40\%$

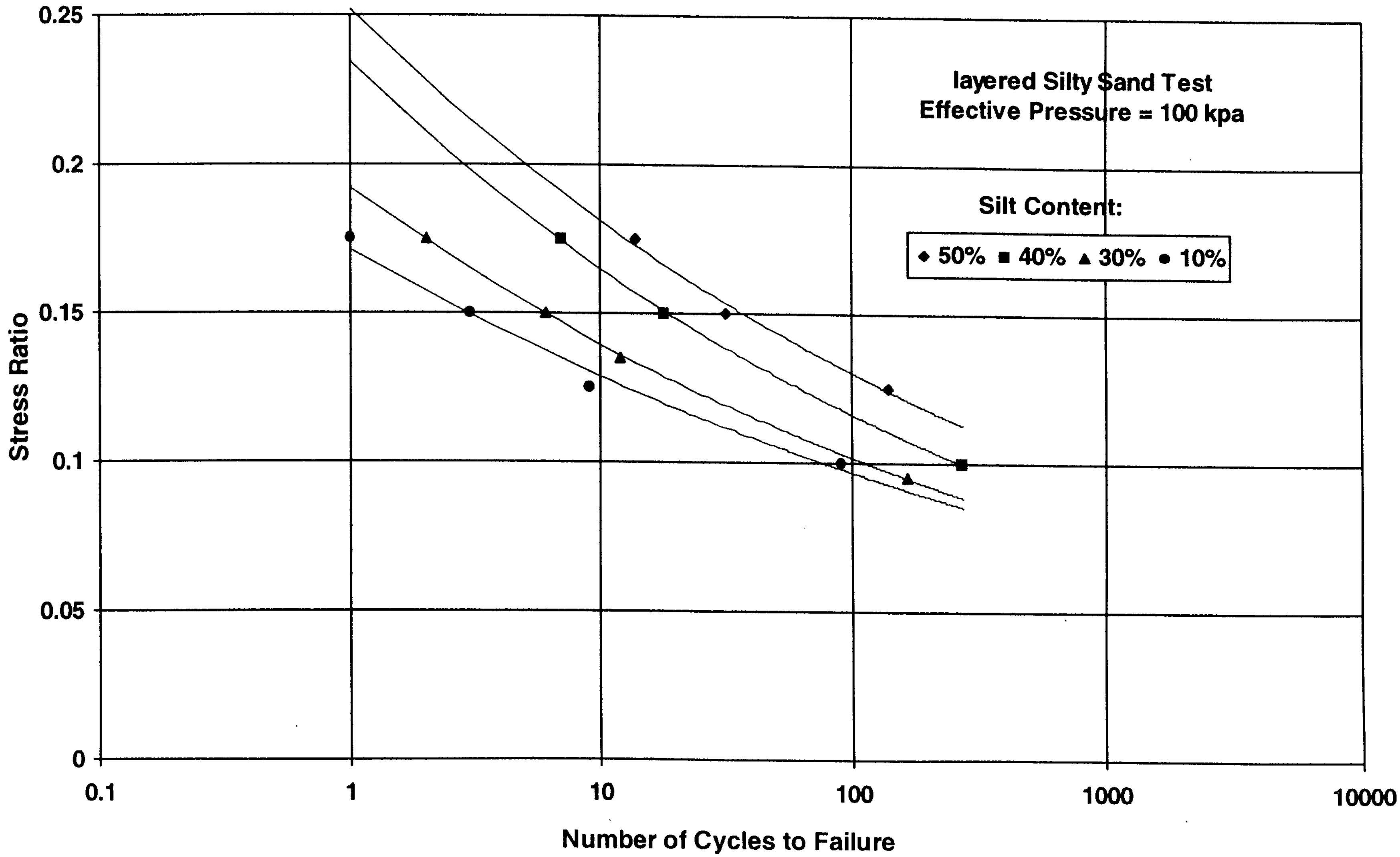

Figure 5. Effect of Silt Content on the Liquefaction of Layered Silty Sands

4.2 Effect of Confining Pressure

Figures 6 and 7 show the effect of variation of effective confining pressure on the liquefaction resistance of silty sands. As the confining pressures increased, the liquefaction resistance of silty sands decreased for both uniform and layered soil conditions.

4.3 Comparison Between Layered and Uniform Soil Conditions

An example of comparison between the liquefaction behavior of layered and uniform soils is shown in Figure 8. The comparison is shown in Figures 9 through 11, as a function of silt content, and in Figures 12 through 14, as a function of effective confining pressure. The results indicated that the liquefaction resistance of layered and uniform soils was not significantly different, despite the fact that the sand fabric produced by the two methods of sample preparation was totally different. This behavior was observed under a wide range of silt contents and confining pressures. Examples of pore water pressure buildup curves for the layered and uniform soil conditions are shown in Figure 15 and 16, and the complete data for these examples are shown in Appendix V. As shown in Figures 15 and 16, the pore water pressure buildup curves for the two methods of sample preparation are similar. The pore water pressure buildup characteristics and liquefaction resistances of the silty sands are not significantly affected by the fabric of soil specimen.

4.3 Effect of Anisotropic Stress Ratio, K_c

This part of the study was undertaken to obtain strengths of layered undrained layered silty sands under cyclic loading conditions simulating those developed during earthquakes on elements of soil behind slopes. The anisotropic stress ratio, K_c is defined as the ratio of major to minor principle stress on a soil element prior to the earthquake. The value of K_c will vary depending on the slope of the soil deposit, and the position of the element of soil within the

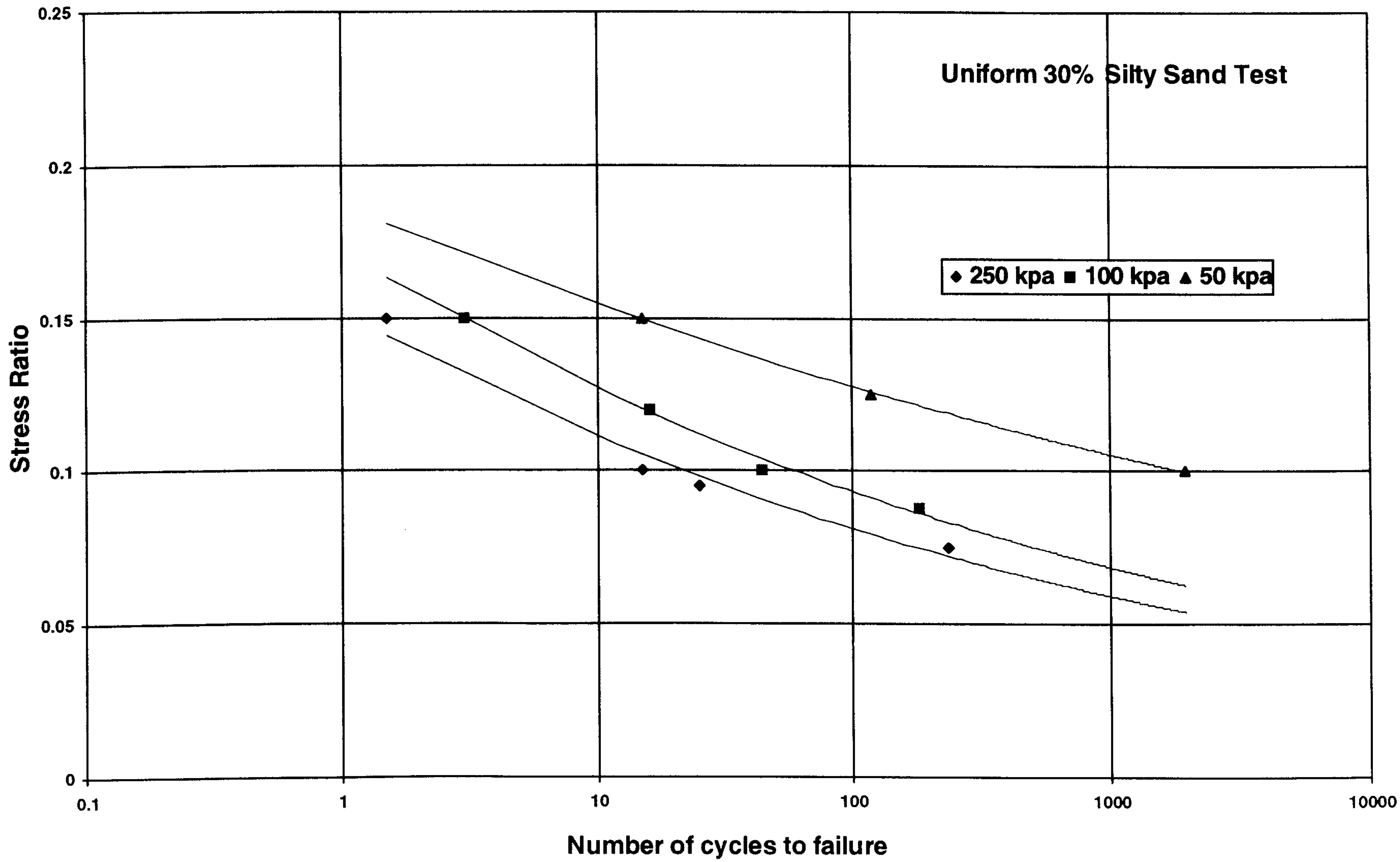

Figure 6. Effect of Confining Pressure on the Liquefaction of Uniform Silty Sands, $D_r = 40\%$

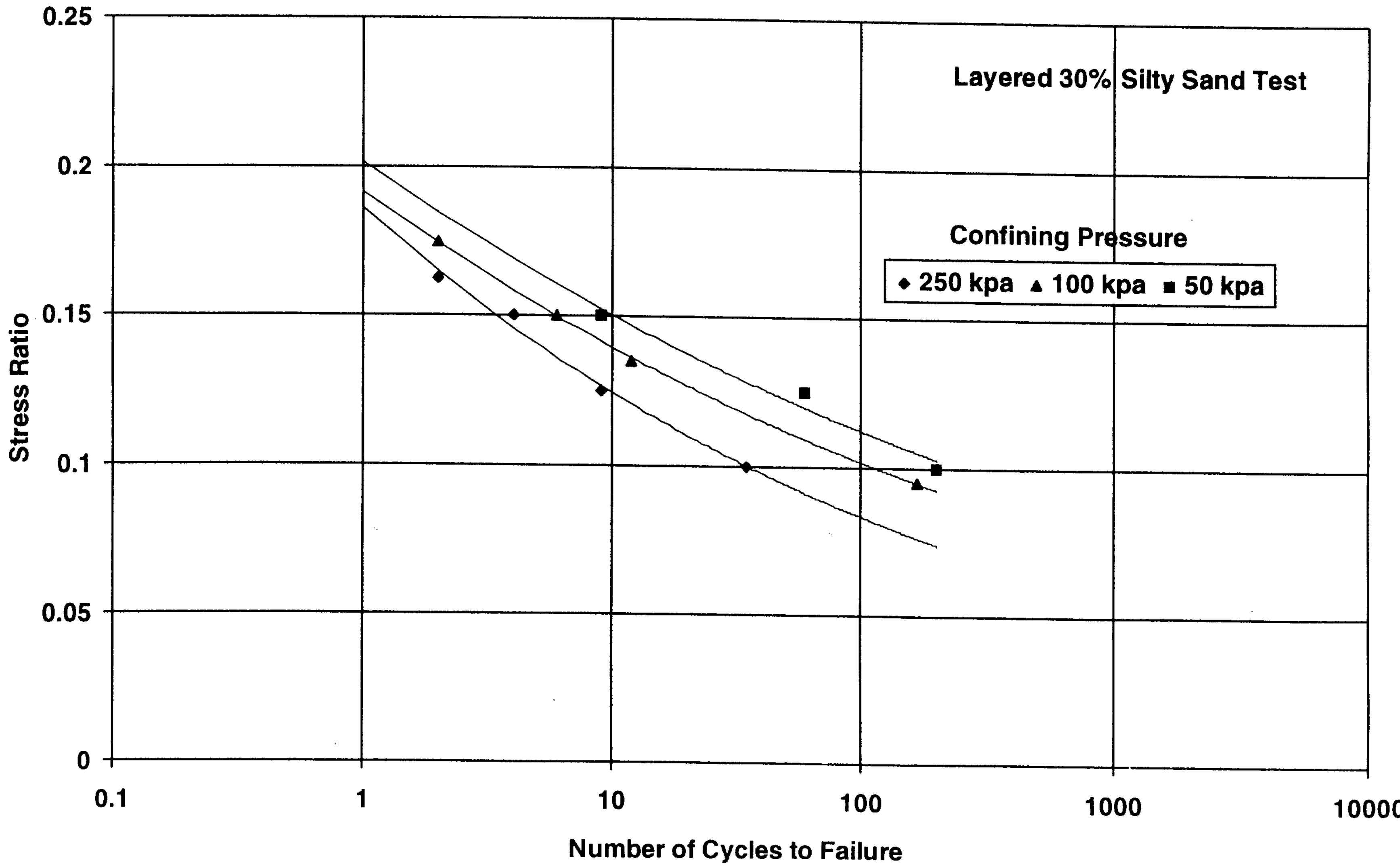

Figure 7. Effect of Confining Pressure on the Liquefaction of Layered Silty Sands

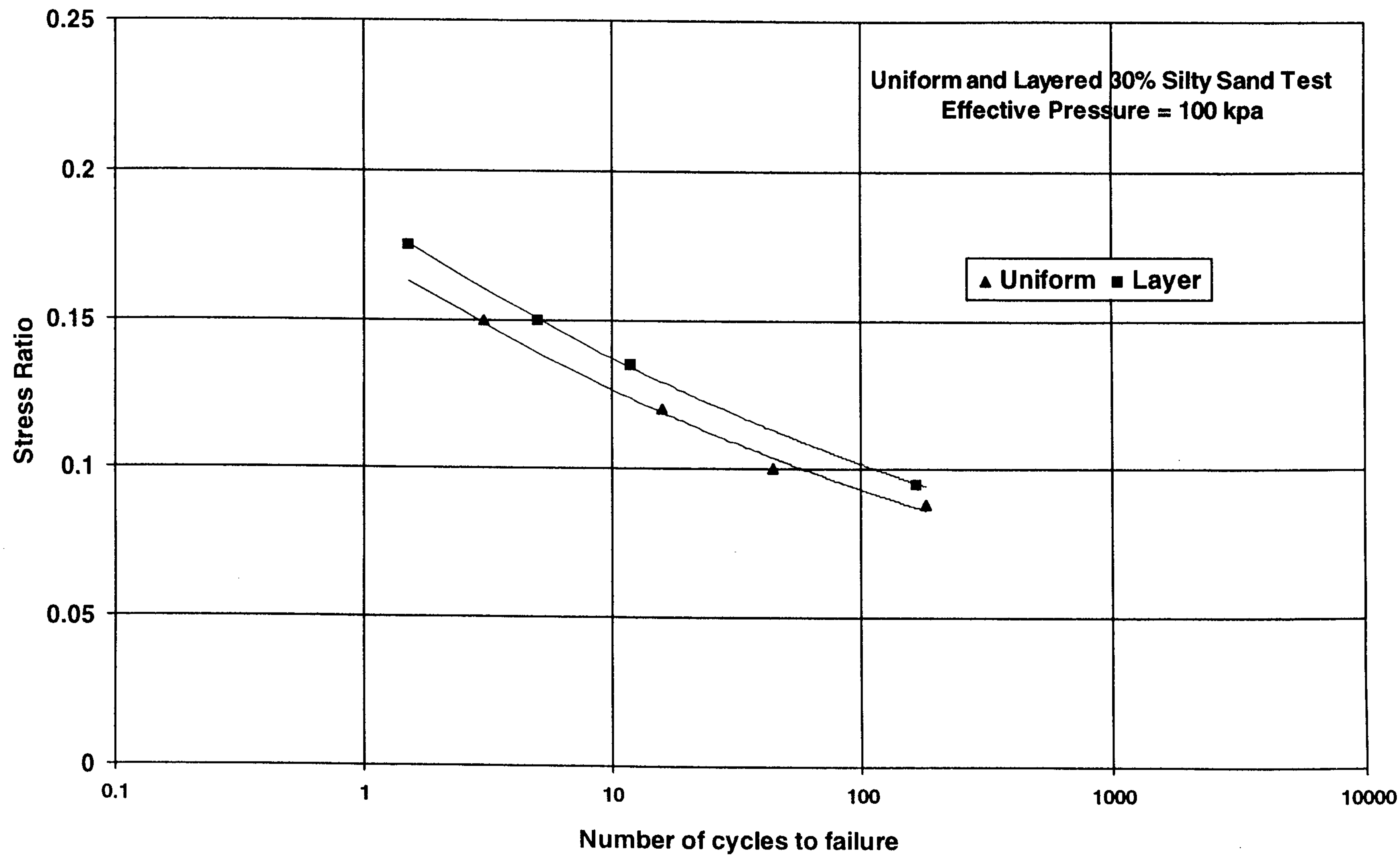

Figure 8. Comparison Between Liquefaction Behavior of Layered and Uniform Soils, $D_r = 40\%$

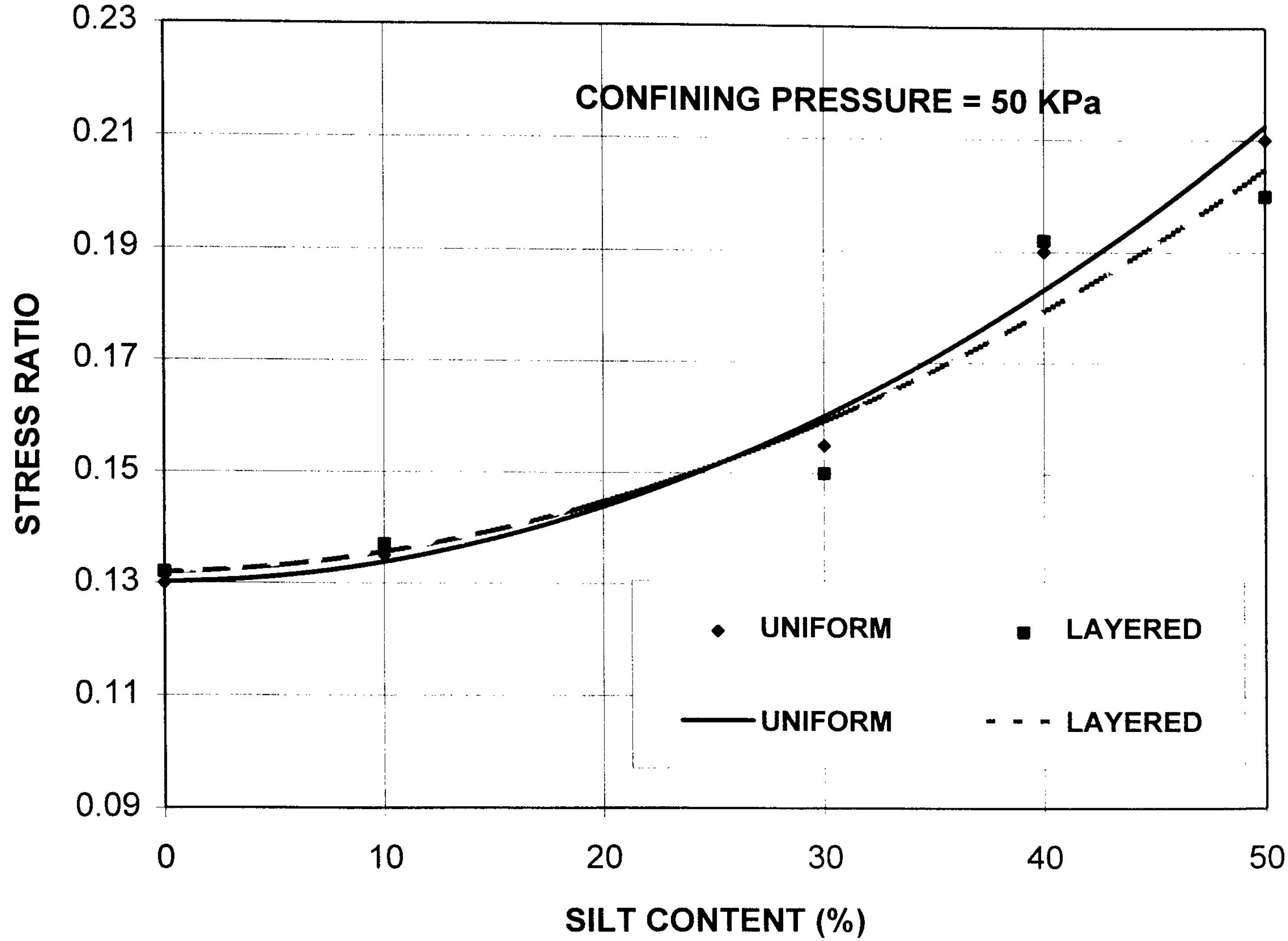

Figure 9. Comparison Between Liquefaction Behavior of Layered and Uniform Soils As a Function of Silt Content; No. of Stress Cycles = 10; Confining Pressure = 50 KPa

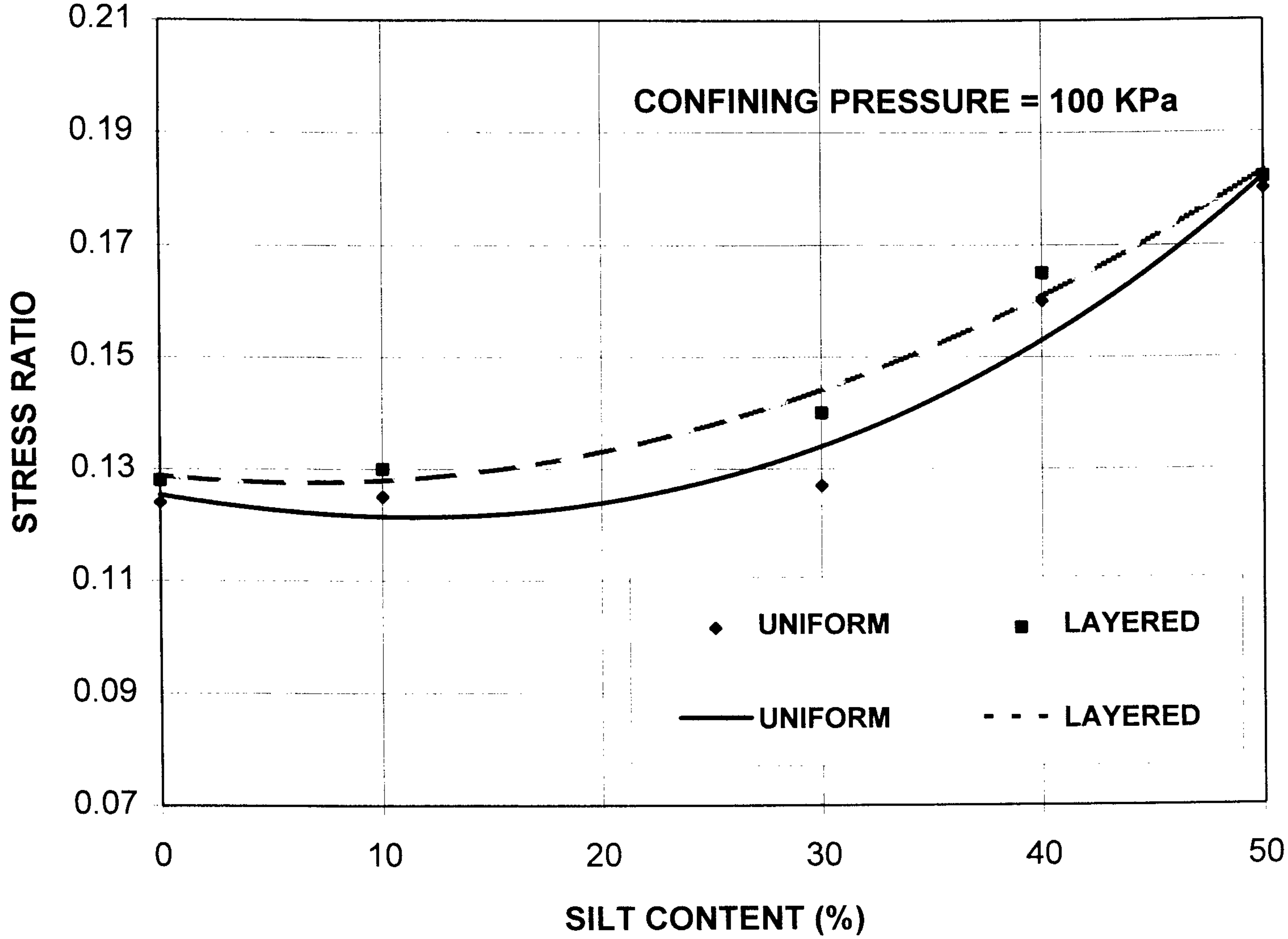

Figure 10. Comparison Between Liquefaction Behavior of Layered and Uniform Soils As a Function of Silt Content; No. of Stress Cycles = 10; Confining Pressure = 100 KPa

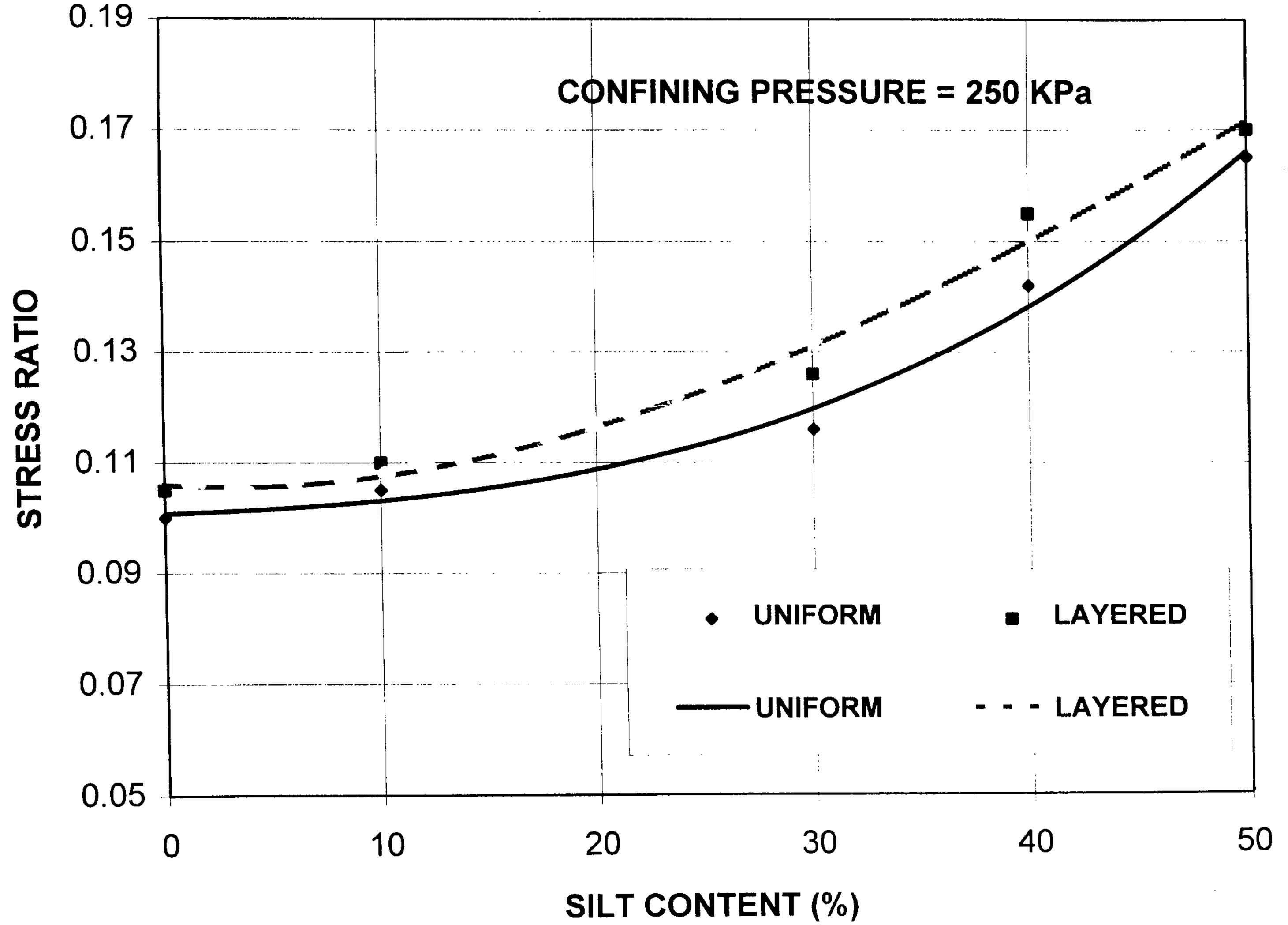

Figure 11. Comparison Between Liquefaction Behavior of Layered and Uniform Soils As a Function of Silt Content; No. of Stress Cycles = 10; Confining Pressure = 250 KPa

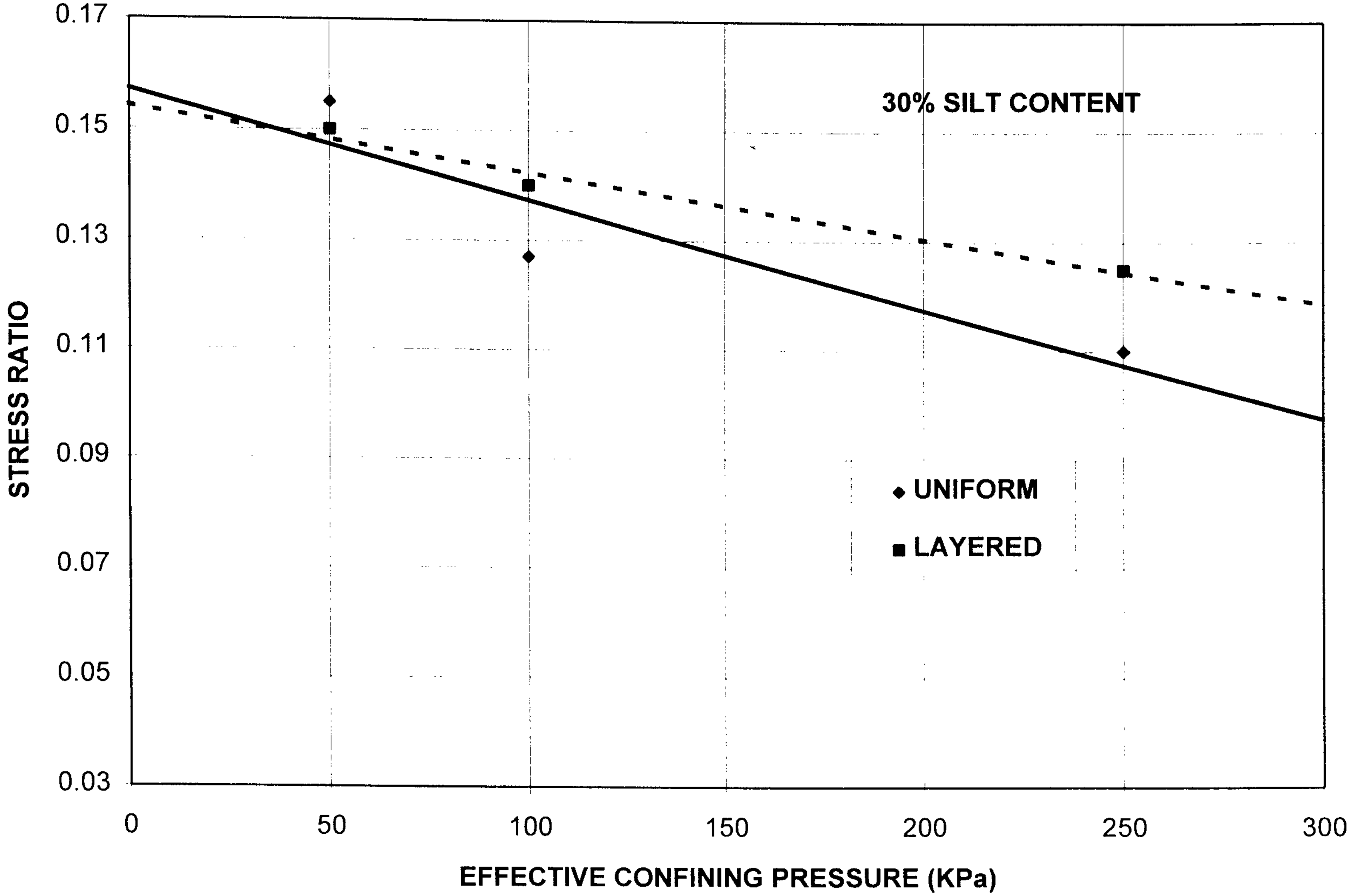

Figure 12. Comparison Between Liquefaction Behavior of Layered and Uniform Soils As a Confining Pressure; No. of Stress Cycles = 10; Silt Content = 30 %

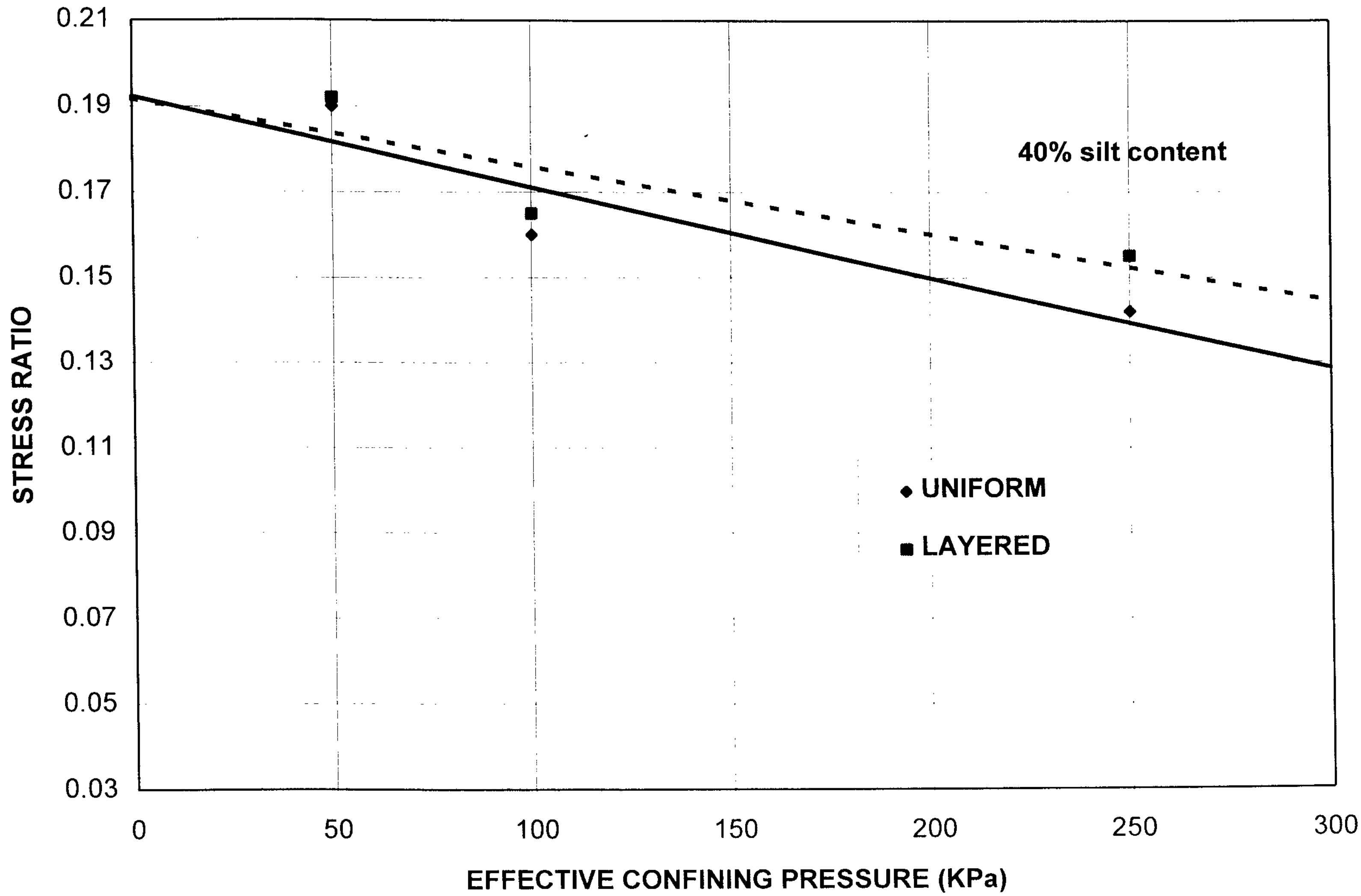

Figure 13. Comparison Between Liquefaction Behavior of Layered and Uniform Soils As a Confining Pressure; No. of Stress Cycles = 10; Silt Content = 40 %

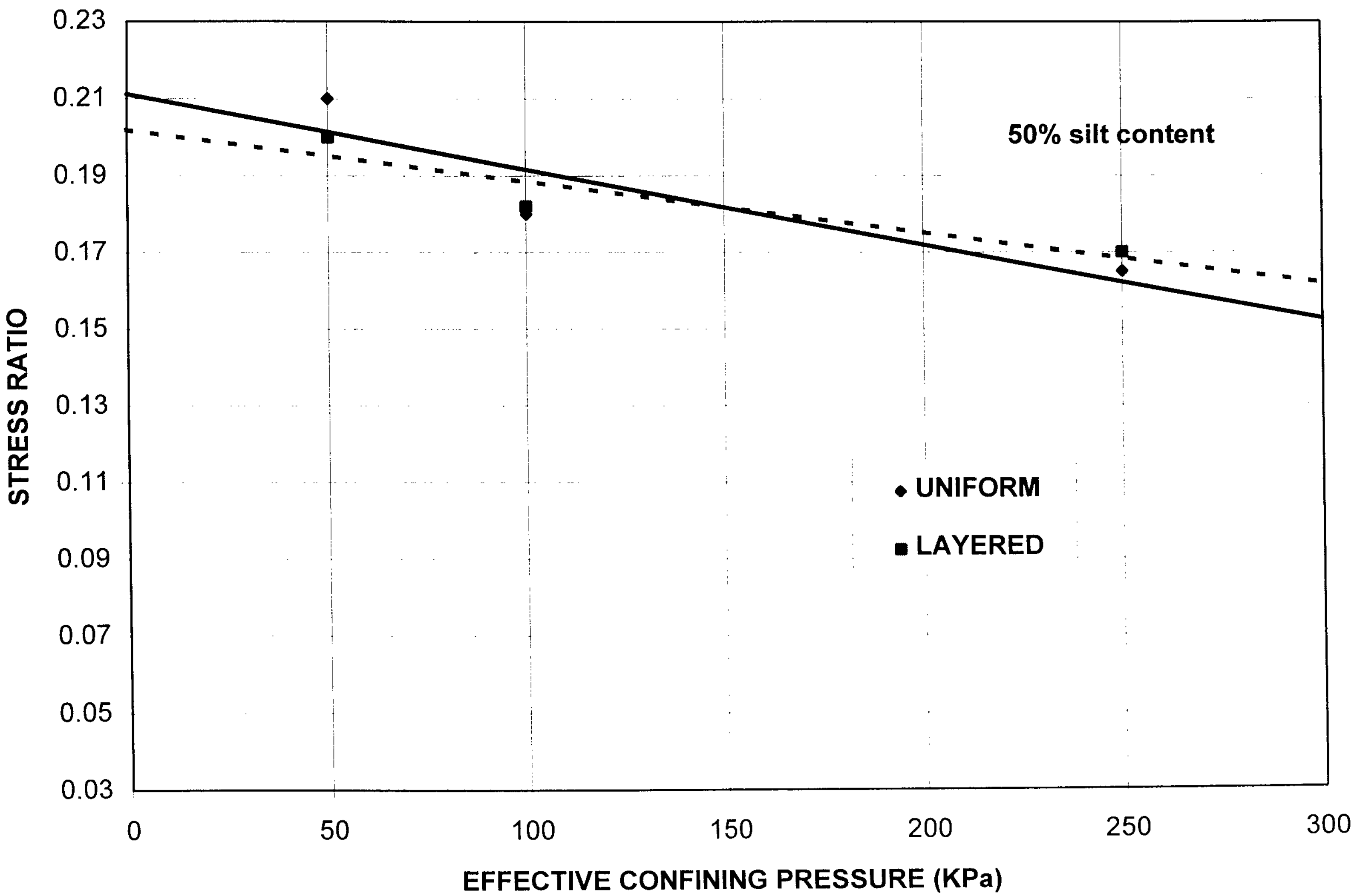

Figure 14. Comparison Between Liquefaction Behavior of Layered and Uniform Soils As a Confining Pressure, No. of stress Cycles = 10; Silt Content = 50 %

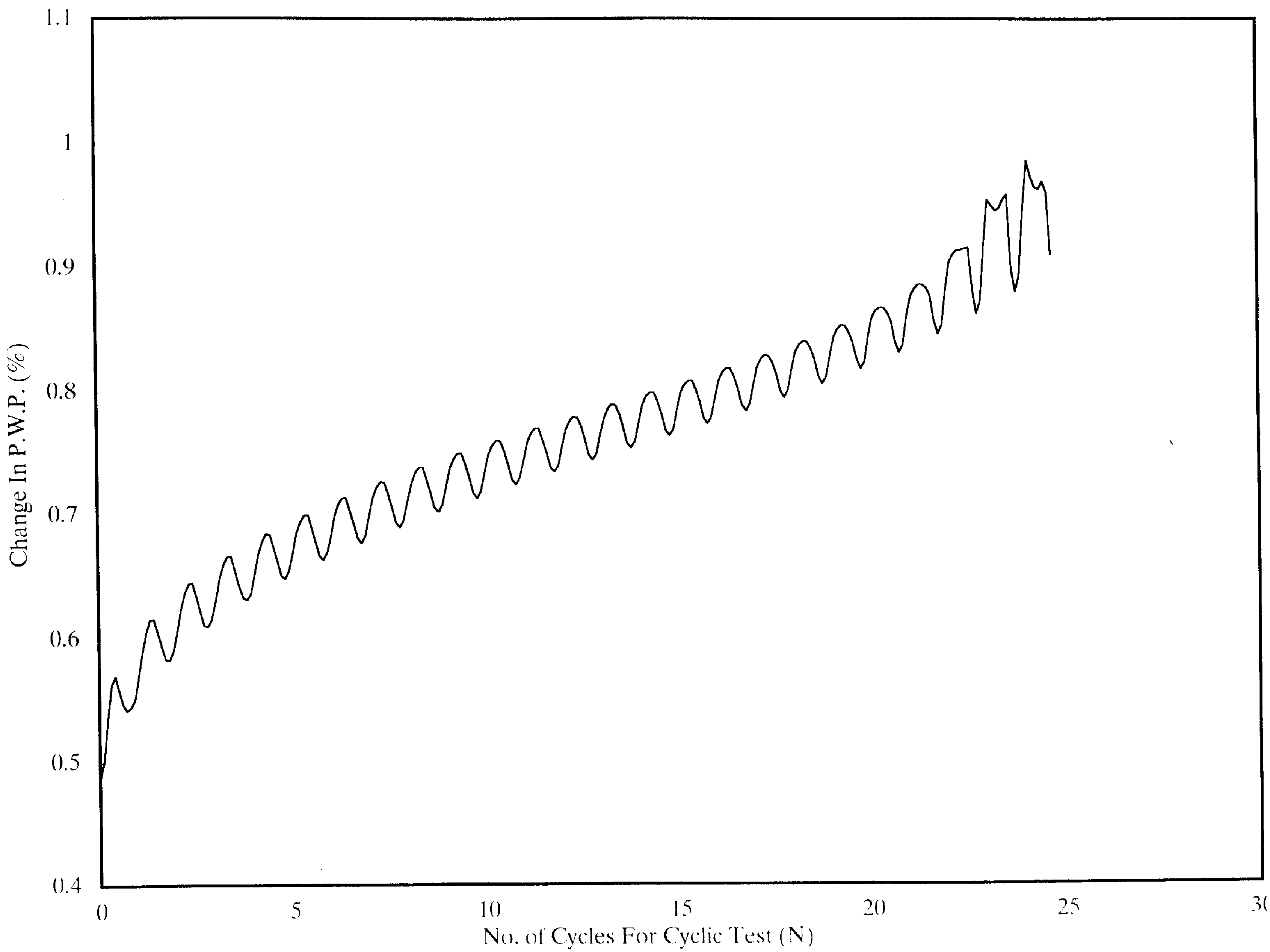

Figure 15. Pore water Pressure Buildup Curve for Uniform Soil Condition. Silt Content = 30%; Confining Pressure = 250 KPa; D_r = 40%

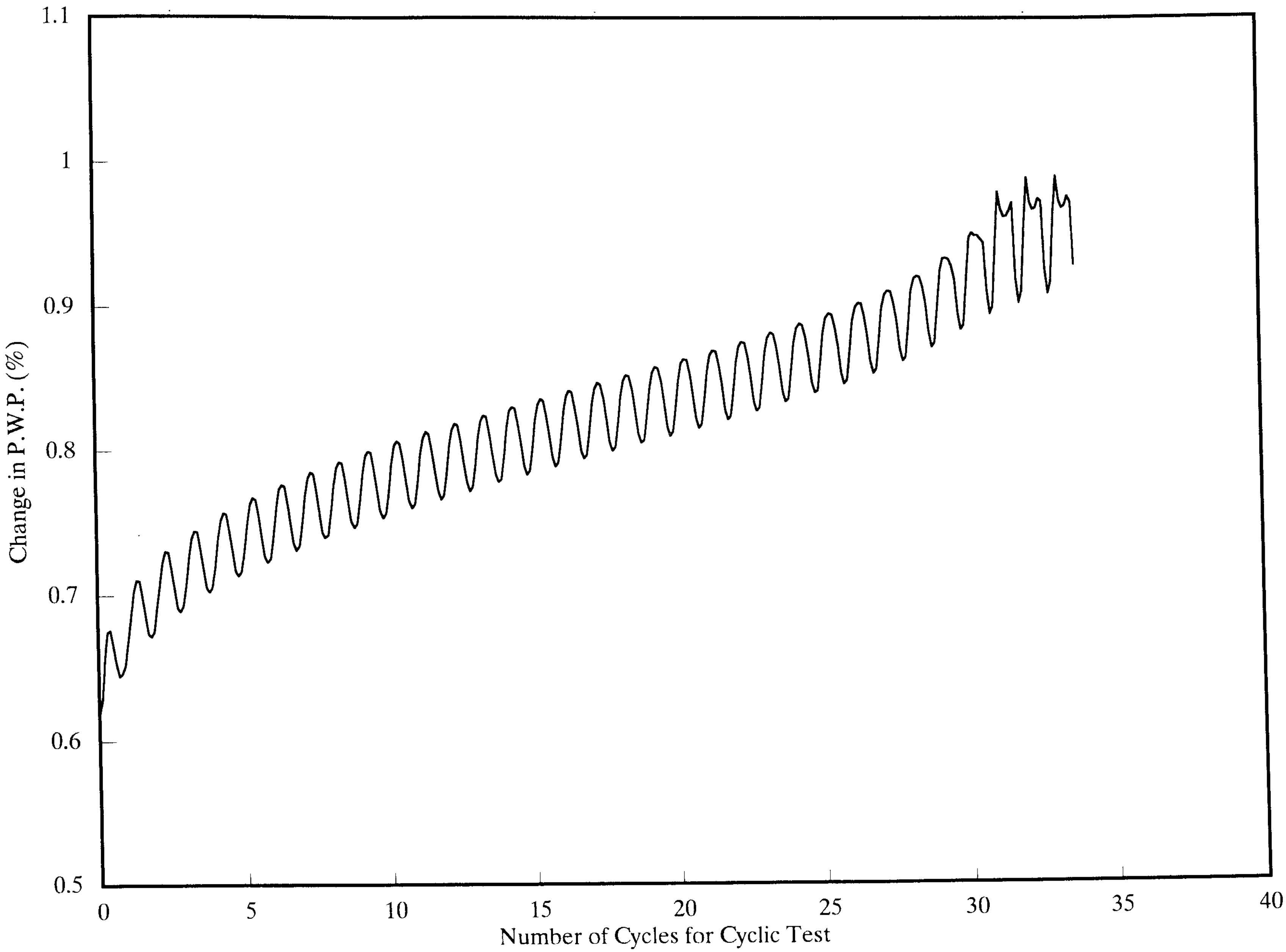

Figure 16. Pore water Pressure Buildup Curve for Layered Soil Condition Silt Content = 30%; Confining Pressure = 250 KPa

embankment. An example of the effect of K_c on liquefaction behavior of layered silty sands is shown in Figure 17. As the value of anisotropic stress ratio, K_c increased, the number of cycles to liquefaction also increased for a given stress ratio for the layered soil condition. The result also implies that the effect of anisotropic soil conditions for layered and uniform soils is similar, and is not significantly affected by the fabric of soil specimens.

5. CONCLUSIONS

A comprehensive experimental program to study the behavior of layered soil conditions was undertaken in which a total of hundred fifty stress-controlled cyclic triaxial tests were performed. The following primary conclusions were obtained as a result of this study.

1. The liquefaction resistance of layered and uniform soils are not significantly different, despite the fact that the soil fabric produced by the two methods of sample preparation is totally different. This behavior was observed for both isotropically and anisotropically consolidated specimens and under a wide range of silt contents and confining pressures. This finding justifies applying the laboratory tests results to the field conditions for the range of variable studied.
2. As the confining pressure increased, the liquefaction resistance of silty sands decreased for both layered and uniform soil conditions.
3. The increase in silt content (percent passing No. 200 sieve) causes the liquefaction resistance of silty sands to increase for both uniform and layered soil conditions.
4. As the value of anisotropic stress ratio, K_c increased, the number of cycles to liquefaction also increased for a given stress ratio for both uniform and layered soil conditions.

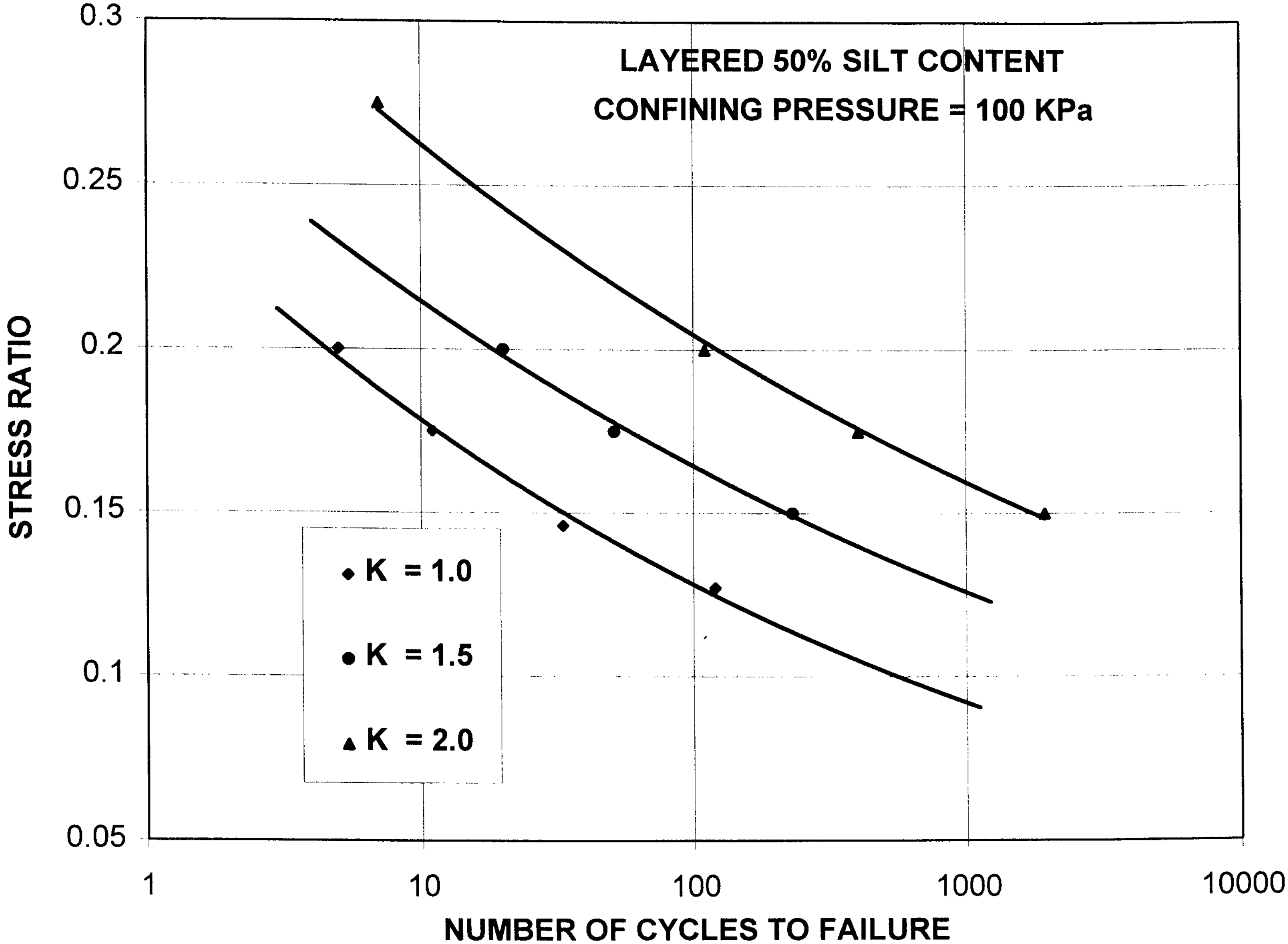

Figure 17. Effect of K_c on Liquefaction Resistance of Layered Silty Sands

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APPENDIX I. IMPACT FOR SCIENCE

The cyclic behavior of layered silty sands is currently poorly understood, although these materials are commonly found in the field where various soil types have been deposited through water by nature or man. This study provides insight for dealing with high hazard earth dams now under seismic review by Army Cops of Engineers. The results of this research may be used for addressing the remediation of high hazard earth dams.

APPENDIX II. RELATIONSHIPS TO OTHER PROGRAMS OR PROJECTS

This research is a collaborative effort by researchers at the University of the District of Columbia (UDC) and U.S. Army Engineer Waterways Experiment Station (WES). The research is performed at the Soil Dynamics and Earthquake Engineering Laboratory of the University of the District of Columbia.

APPENDIX III

SCIENTIFIC PERSONNEL SUPPORTED BY THIS PROJECT AND DEGREES AWARDED DURING THIS REPORTING PERIOD

Scientific Personnel: F. Amini, Gui Qi

Degrees Awarded:

Joseph Bastian, B.S., Civil Engineering, May 1995

Michael Le, B.S., Civil engineering, May 1996

Yevgeny Smolkin, B.S. Mechanical Engineering, May 1995

LIST OF MANUSCRIPTS SUBMITTED OR PUBLISHED UNDER ARO SPONSORSHIP DURING THE REPORTING PERIODS, INCLUDING JOURNAL REFERENCE

Research recently completed. Several manuscripts are being prepared for publication. They will be sent shortly.

REPORT OF INVENTIONS

None

TECHNOLOGY TRANSFER

This research was a collaborative effort by researchers at the University of the District of Columbia (UDC) and U.S. Army Engineer Waterways Experiment Station (WES). The research was performed at the Soil Dynamics and Earthquake Engineering Laboratory of the University of the District of Columbia. Dr. Joseph Koester of Waterways Experiment Station, Earthquake Engineering and Geosciences Division, visited the laboratory twice during the period. Discussions were held concerning the research plan and procedures during Dr. Koester's visits.

APPENDIX IV
FARSHAD AMINI

SUMMARY OF SCHOLARLY ACTIVITIES (GRANT PERIOD 1993 -1996)
PARTIAL LIST

RESEARCH GRANTS

Title:	Behavior of Stratified Sand-Gravel Composites under seismic Liquefaction Conditions
PI:	F. Amini
Total Amount:	$ 158000.0 (FUNDED)
Supported by:	National Science Foundation (NSF)

Title:	Research Equipment for Soil Dynamics Test and Study of the Effect of Time on Dynamic Soil Properties. This grant provided both salary (about 60K) and equipment funds including cost sharing (60K) (Indirect cost: 22K)
PI:	F. Amini
Total Amount:	$ 120,000.0 (FUNDED)
Supported by:	National Science Foundation (NSF)

Title:	Active Control of Structures Instrumented with Optical Fiber Sensors under Earthquake Loading. (Simulation Studies as well as Experiments on Shake Table)
PI:	J. C. S. Yang, G. Z. Qi, F. Amini, and J. Sirkus
Total Amount:	$ 180,000.0 (FUNDED)
Supported by:	NSF

Title:	Identification and Active Control of Structures Under Earthquake Loading
PI:	J. C. S. Yang, G. Z. Qi, and F. Amini,
Total Amount:	$ 50,000.0 (FUNDED)
Supported by:	NSF

Title:	Performance Tests for Model Sand Filters
PI:	F. Amini and F. F. M. Chang
Total Amount:	$ 10,000.0 (FUNDED)
Supported by:	D.C. Government
Date:	1993

Title:	An Experimental Study of the Optimal Thickness of Sand Layer in a Sand Filter Water Quality Structure
PI:	F. Amini and F. F. M. Chang
Total Amount:	$ 31,733.0 (FUNDED) (Revised Budget, $ 10,675.0 Federal, $ 20,968.0 Non-Federal)
Supported by:	U.S. Geological Survey, Dept. of Interior

SUMMARY OF SCHOLARLY ACTIVITIES (1993 -1996) CONTINUED

RESEARCH GRANTS (PARTIAL LIST)

Title:	Definition of Groundwater Flow in the Water Table Aquifer of the Downtown Washington D.C. Area
PI:	F. Amini
Total Amount:	$ 42,185.0 (FUNDED) (Revised Budget, $ 11,589.0 Federal, $ 30,569.0 non-Federal)
Supported by:	U.S. Geological Survey, Dept. of Interior

Title:	Definition of Groundwater Flow and Water Quality in the Water Table Aquifer of the Southern Anacostia River Basin
PI:	F. Amini
Total Amount:	$ 20,526.0 (FUNDED)
Supported by:	U.S. Geological Survey, Dept. of Interior

PROFESSIONAL SERVICE

Member of Editorial Board, Journal of Geotechnical Eng., ASCE. Reviewed and coordinated journal papers for the J. of Geotech. Eng., ASCE (1990-Present)

Member of Advisory Committee, The First International Conference on Composites in Infrastructure (ICCI '96), Sponsored By NSF and U. of Arizona, Tucson, Arizona, January 15-17, 1996.

PUBLICATIONS (GRANT PERIOD 1993-1996)
PARTIAL LIST

CHAPTERS IN BOOKS

Qi, G. Z., Yang, J. C. S., and Amini, F. (1996). "Neural Network for Identification and Control of Civil Engineering Structures", Chapter in a Book entitled Artificial Neural Network for Civil Engineers: Fundamentals and Applications, ASCE, New York, N.Y.

OTHER PUBLICATIONS

Amini, F. (1993). "Effect of Confining Pressure on Dynamic Soil Properties Using Improved Transfer Function Methods," Journal of Soil Dynamics and Earthquake Engineering, Vol. 12, No. 11, Nov., 145-147.

Amini, F. and Smith, R. L. (1995). "Peak Flow Rates and Volumes Predictions Using Frequency Equivalent Hydrographs," Journal of Water Resources, Planning and Management, ASCE, Vol. 121, No. 5, Sept., 359-364.

Qi, G. Z., Chen, H. M. Tsai, K. H, Yang, J. C. S., and Amini, F. (1995). "Neural Networks for Structure Control," Journal of Computing in Civil Engineering, ASCE, Vol. 9, No. 2, April., 168-176.

Qi, G. Z., Chen, H. M. Tsai, K. H, Yang, J. C. S., and Amini, F. (1995). "Neural Network for Structural Dynamic Model Identification," Journal of Engineering Mechanics, ASCE, Vol. 121, No. 12, December,

Amini, F., (1995). "Time Effects on Dynamic Soil Properties Under Random Excitation Conditions," Journal of Soil Dynamics and Earthquake Engineering, Vol. 14, No. 6, 439-443.

Fahoum, K., Aggour, M. S., and Amini, F., (1996). "Dynamic Properties of Cohesive Soils Treated with Lime," Journal of Geotechnical Engineering, ASCE, Vol. 122, No. 5, May, 382-389.

Khalilian, A. and Amini, F., (1996). "A Case of A Residential Foundation Failure and Preservation by Pressure Grouting," Journal of Performance of Constructed Facilities, ASCE, Vol. 10, No. 4, November, 159-163.

Amini, F. (1996). Discussion of "System Identification and Its Application to Estimating Soil Properties by S. Glaser," Journal of Geotechnical Engineering, ASCE, Vol. 122, No. 10

Amini, F. and Khalilian, A., (1997). "Old Post Office Foundation Failure Investigation," Journal of Performance of Constructed Facilities, ASCE, Vol. 11, No. 1, February.

PUBLICATIONS (CONTINUED)

Amini, F. and Khalilian, A., (1997). "Old Post Office Foundation Failure Investigation," Journal of Performance of Constructed Facilities, ASCE, Vol. 11, No. 1, February.

Amini, F. (1996)."Effect of Filter Thickness on the Efficiency of Sand Filter Water Quality Structure," Water Quality Journal of Canada, Vol. 31, No. 4, Nov., 801-807

Amini, F., (1995). "A Nonlinear Hydrograph for Volume Predictions, in Water Resources Engineering, Epsy, ed., ASCE, New York, N.Y., Aug.

Amini, F., Chen, H. M., Qi, G. Z., Yang, J. C. S., (1996). "Neural Network Based Active Control Experiments on Model Structure, Proceedings of the First European Conference on Structural Control, World Scientific Publishing Co., Barcelona, Spain, May.

Yang, J. C. S., Amini, F., Sirkus, J., Qi, G. Z. (1993). "Active Control of Structure Instrumented with Optical Fiber Sensors," Presented at the First NSF Coordination Meeting, Ann Arbor, Michigan.

Amini, F. (1993). "Time Dependent Nature of Dynamic Soil Behavior Under Earthquake Loading, State-of-The-Art," Proceedings of the Second International Conference on Soil Mechanics and Foundation Engineering, Tehran, Iran, Nov.

Amini, F., Chen, H. M., Qi, G. Z., and Yang, J. C. S. (1994). "Neural Network for Identification and Control of Structures," Proceedings of the First International Conference on Control, Pasadena, CA, Aug, 43-51.

Matheson, G. M., Flick, B. A., and Amini, F. (1995). "Development of Groundwater Contour Map for the Water Table Aquifer of the Atlantic Coastal Plain Deposits of Washington, D.C." D.C. Water Resources Research Center Report No. 156.

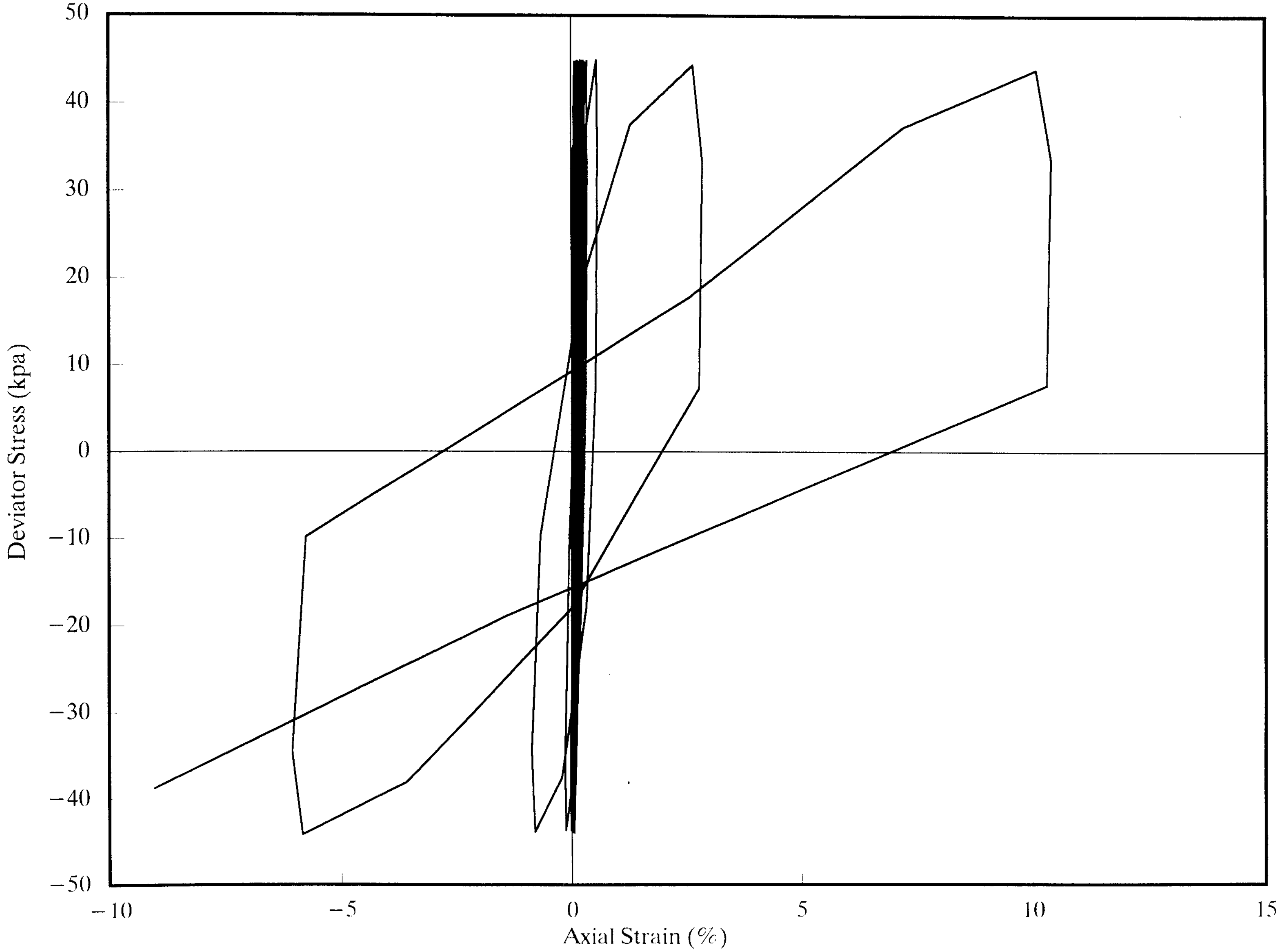
Amini, F., Chang, F. F. M., and Schneider, J. (1994). " An Experimental Study of the Optimal Thickness of a Sand Layer in a Sand Filter Water Quality Structure," D.C. Water Resources Research Center Report, Report No. 153.

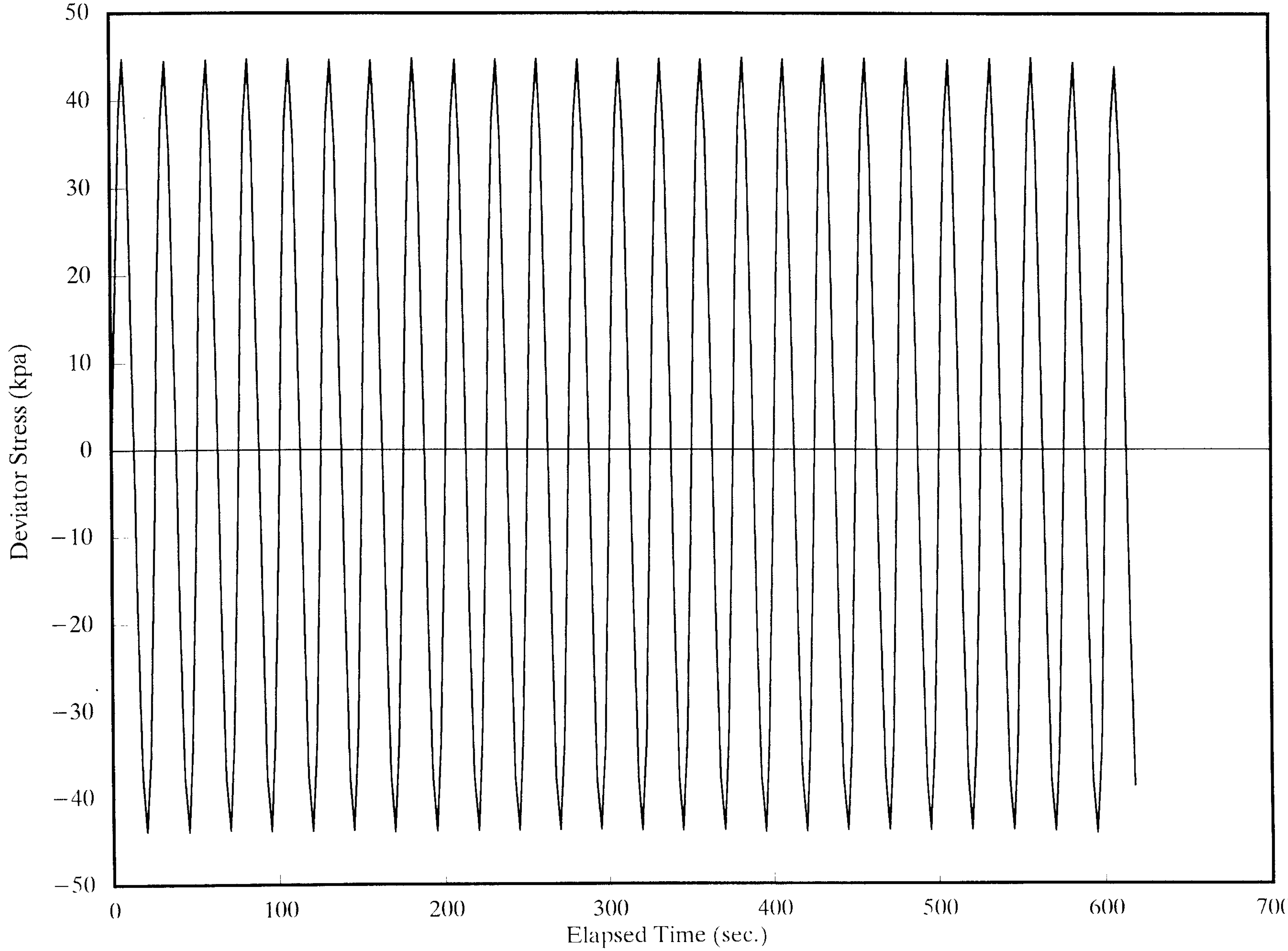
Matheson, M. M., Schneider, J., Zmijewski, D., and Amini, F. (1994). "Definition of Groundwater Flow in the Water Table Aquifer of the Southern Anacostia River Basin," D.C. Water Resources Research Center Report No. 147.

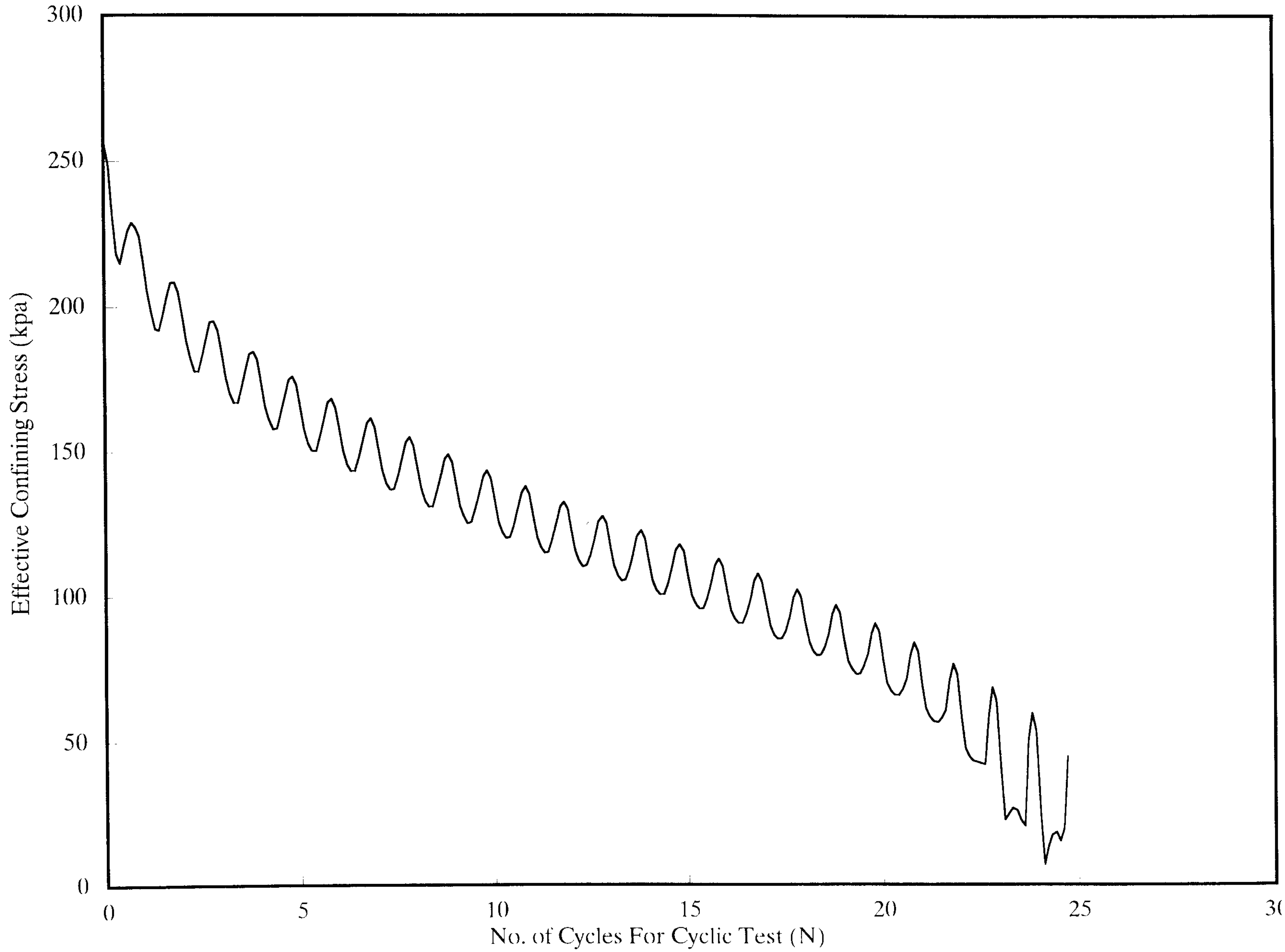
Amini, F., and Chang, F. F. M. (1994). "Model of a Stormwater Management Facility," A Report to the Environmental Regulation Administration, Government of the District of Columbia. April.

APPENDIX V. EXAMPLES OF DATA OBTAINED DURING CYCLIC TESTS

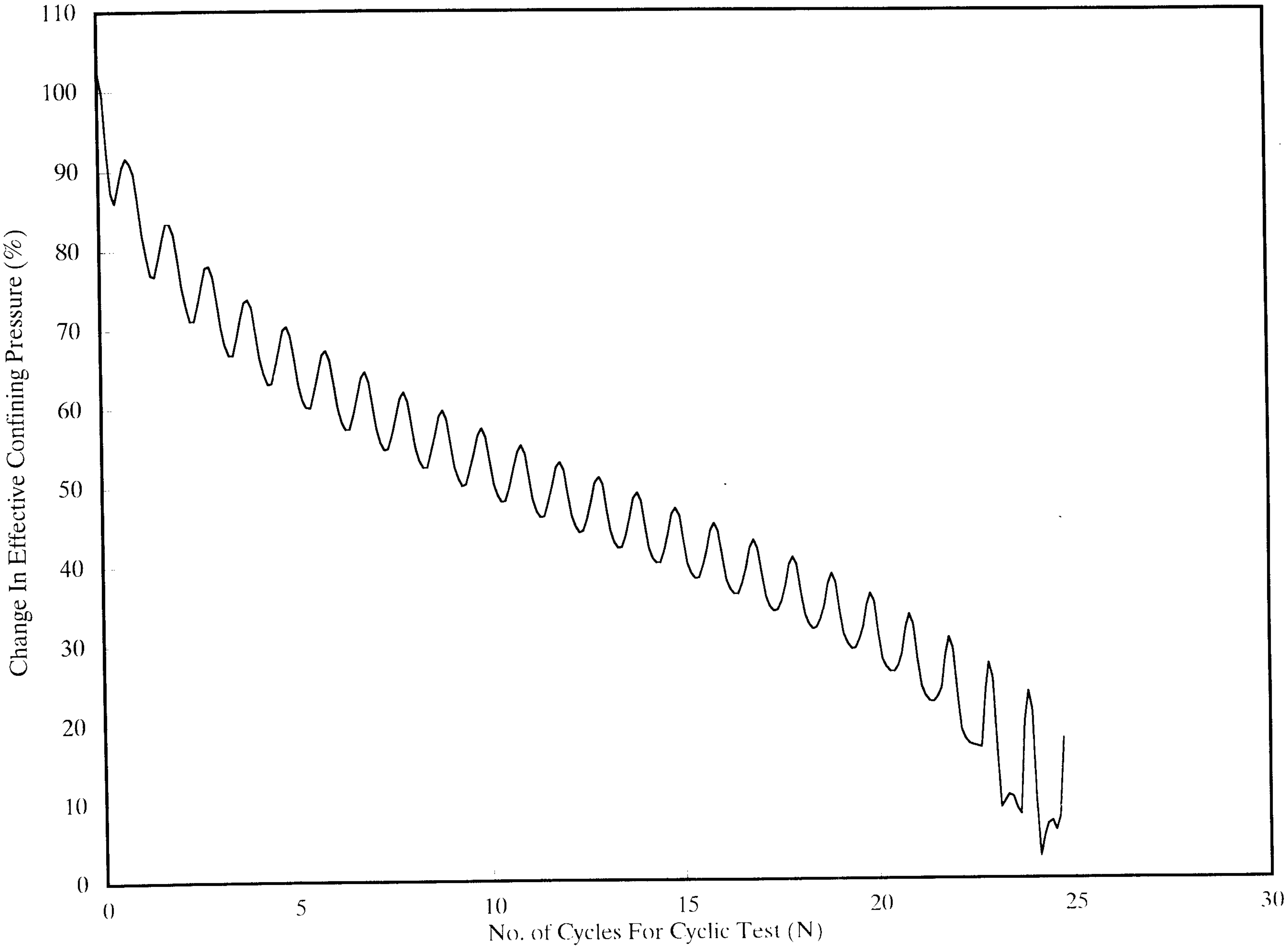
EXAMPLES OF DATA: UNIFORM SOIL CONDITION; SILT CONTENT = 30%; CONFINING PRESSURE = 250 KPa; D_r = 40%

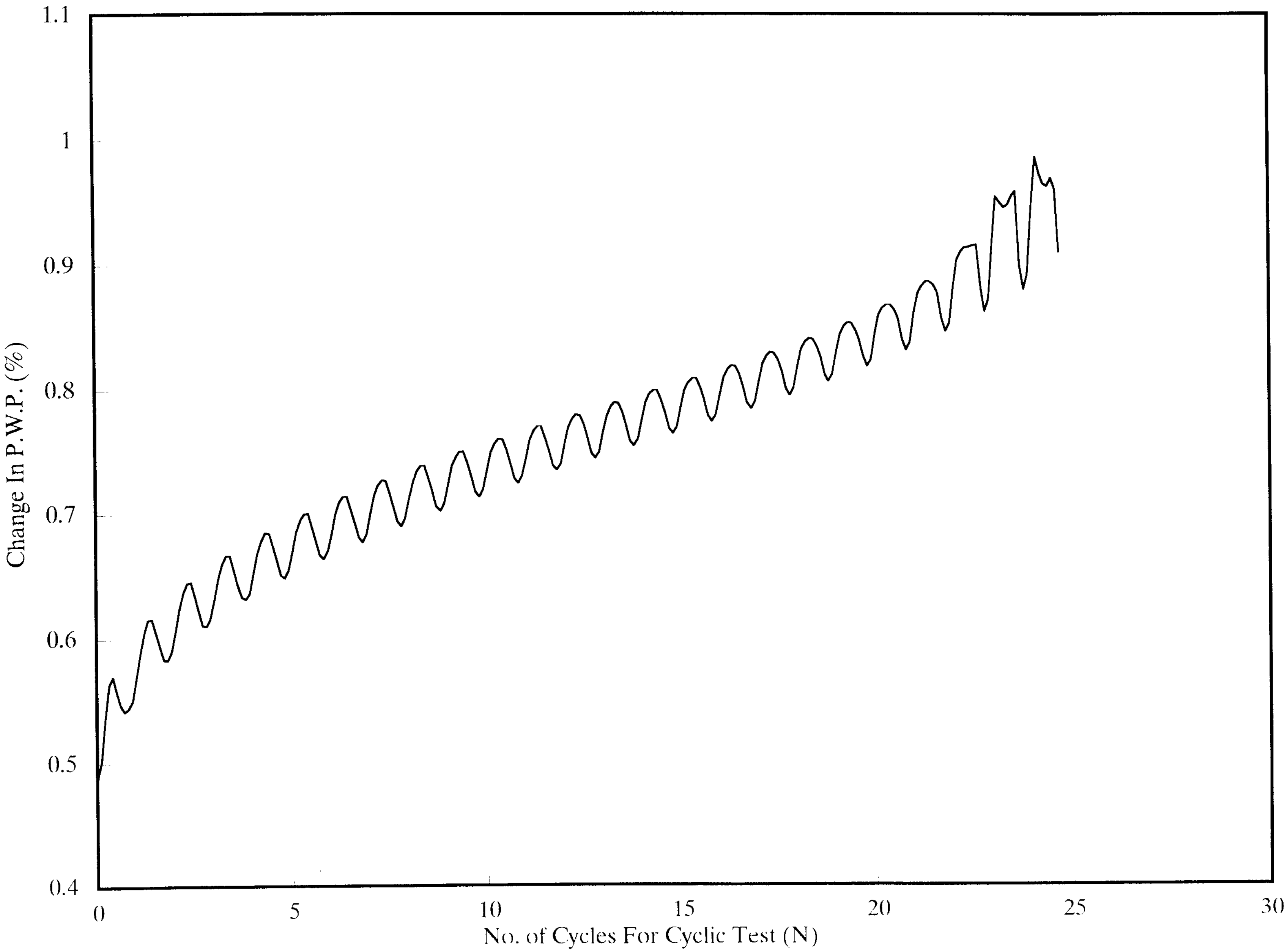

50
40
30
20
10
0
−10
−20
−30
−40
−50
Deviator Stress (kpa)
−10
−5
0
5
10
15
Axial Strain (%)


50
40
30
20
10
0
−10
−20
−30
−40
−50
Deviator Stress (kpa)
0
100
200
300
400
500
600
700
Elapsed Time (sec.)

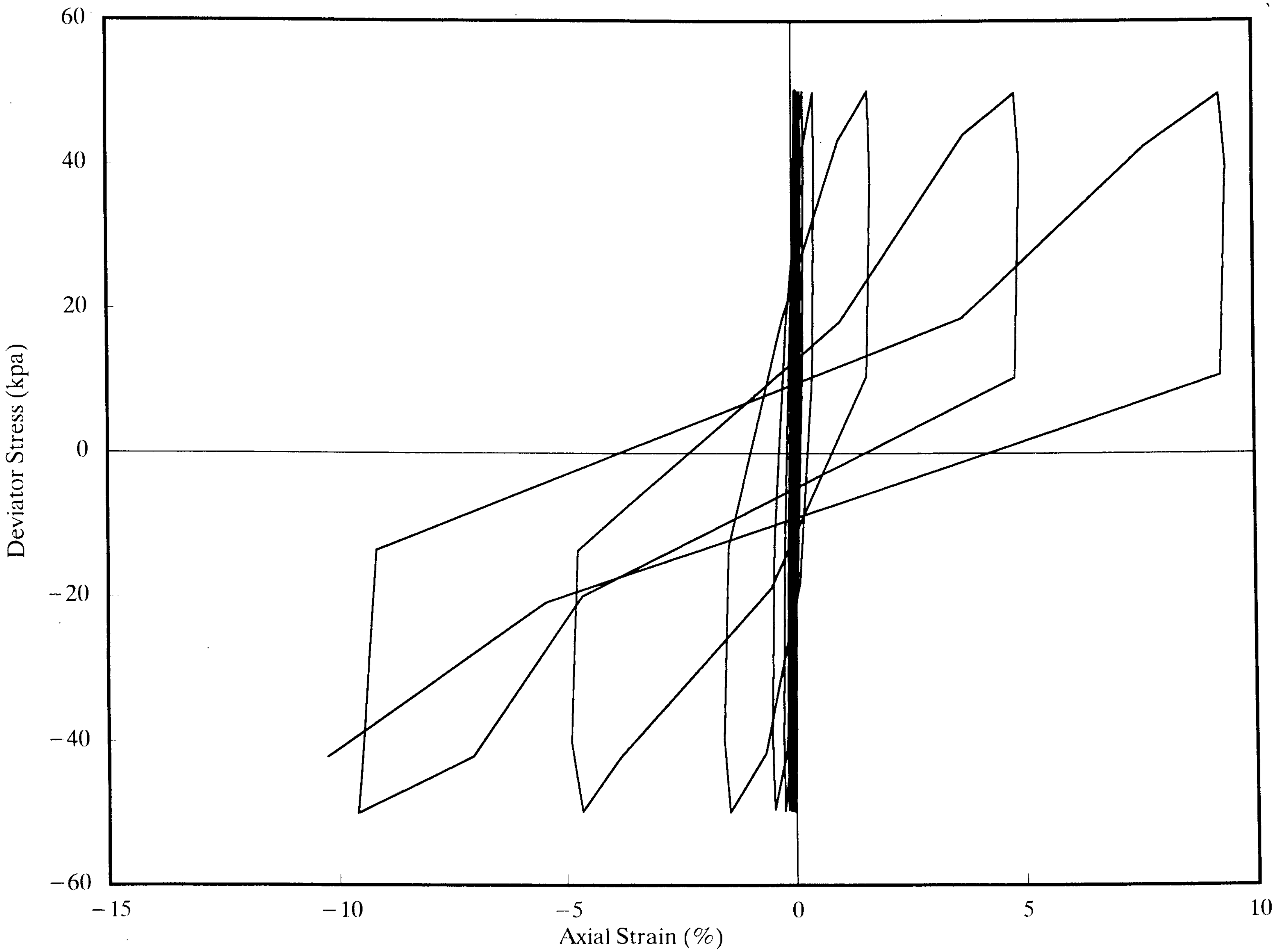


300
250
200
150
100
50
0
Effective Confining Stress (kpa)
0
5
10
15
20
25
30
No. of Cycles For Cyclic Test (N)

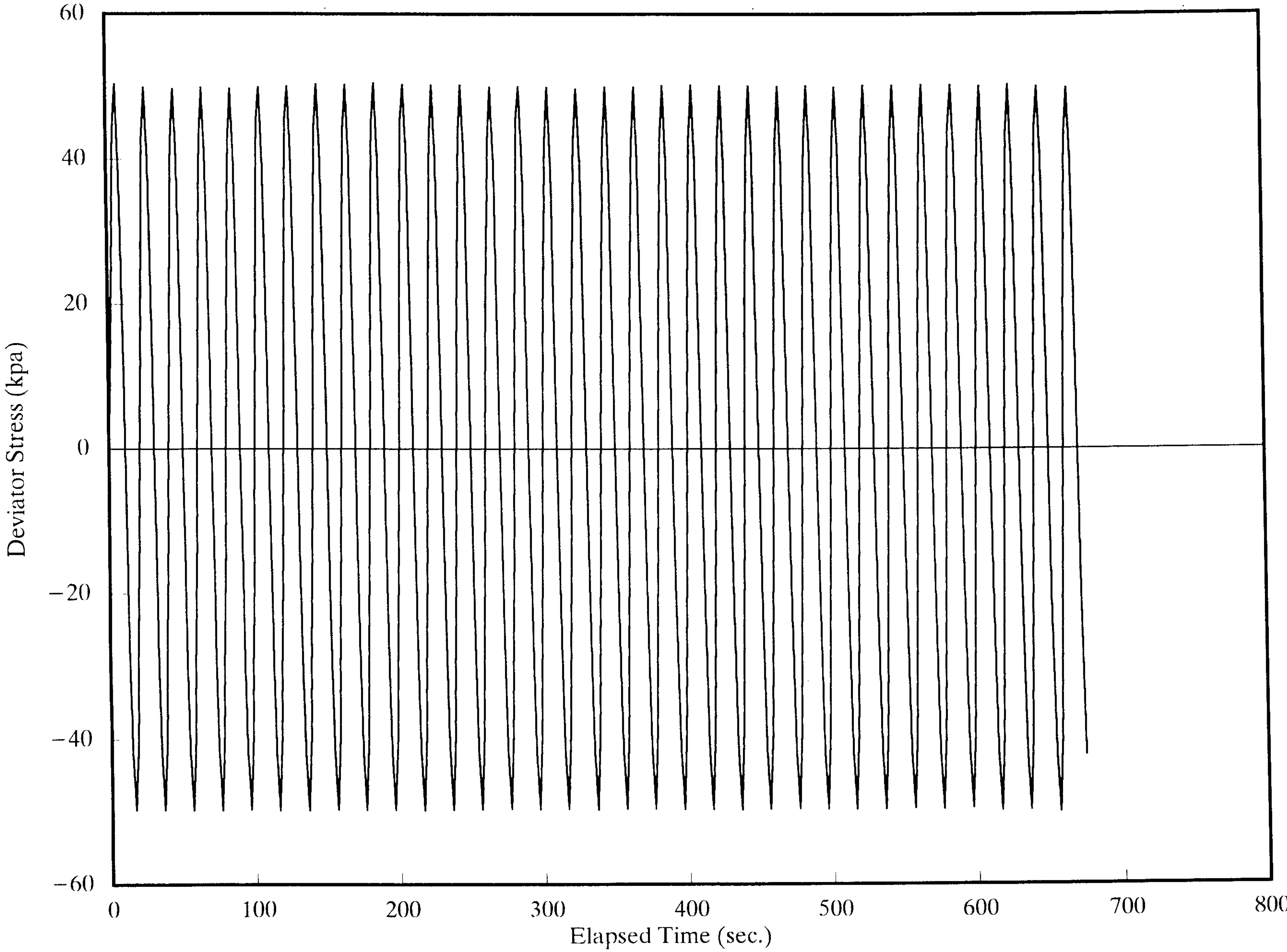

110
100
90
80
70
60
50
40
30
20
10
0
Change In Effective Confining Pressure (%)
0
5
10
15
20
25
30
No. of Cycles For Cyclic Test (N)

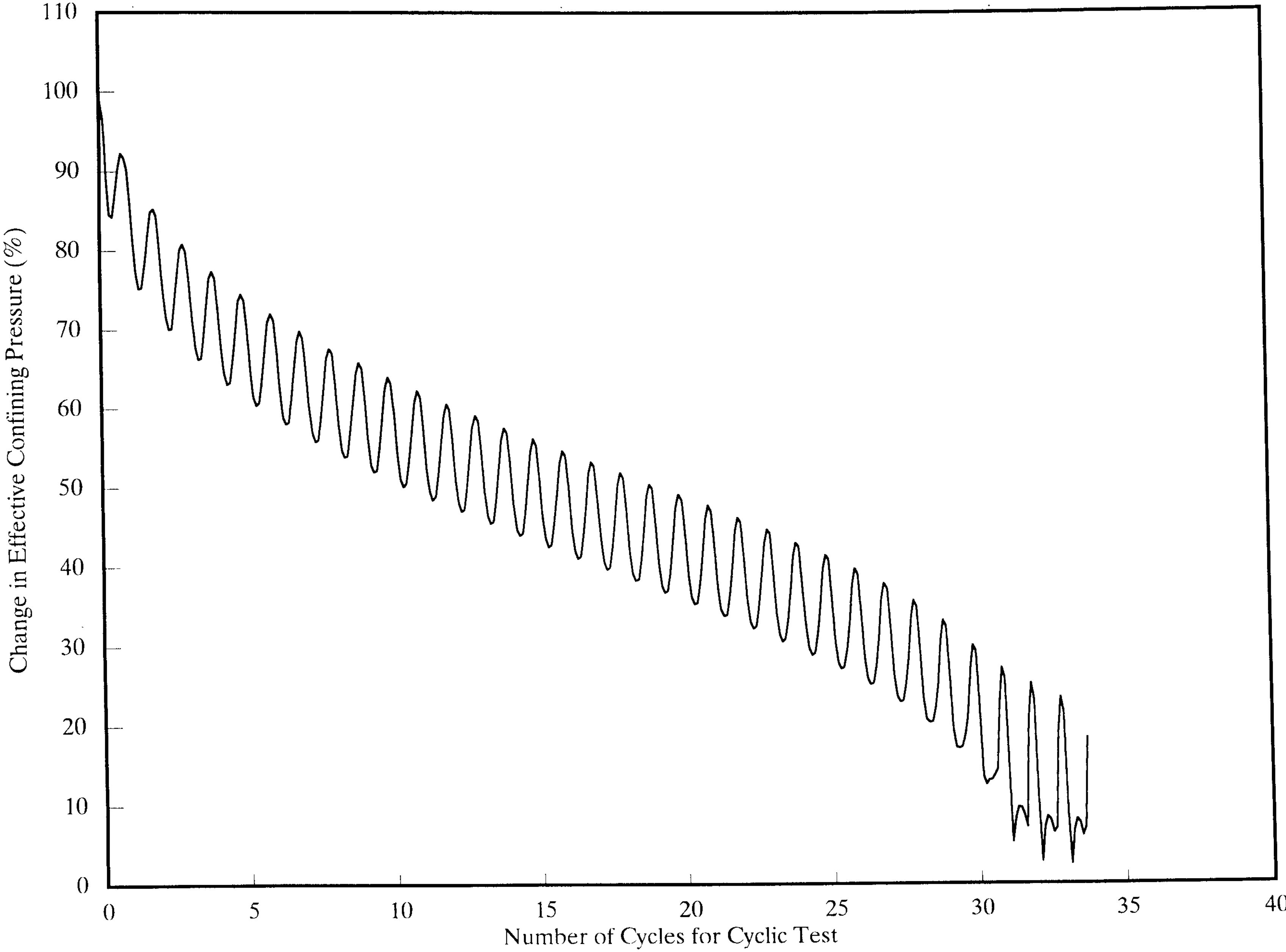

1.1
1
0.9
0.8
0.7
0.6
0.5
0.4
Change In P.W.P. (%)
0
5
10
15
20
25
30
No. of Cycles For Cyclic Test (N)

EXAMPLES OF DATA: LAYERED SOIL CONDITION; SILT CONTENT = 30%; CONFINING PRESSURE = 250 KPa

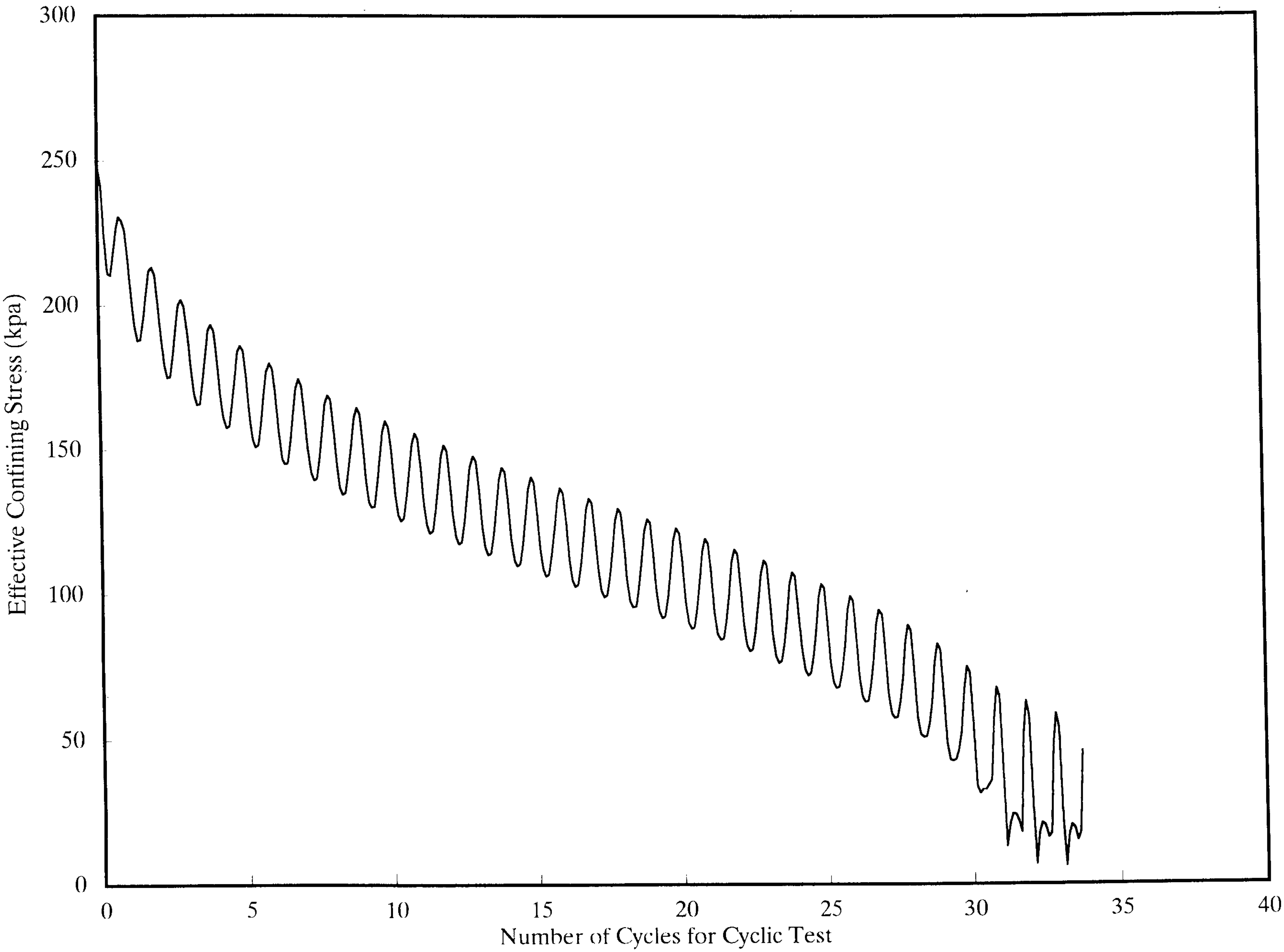


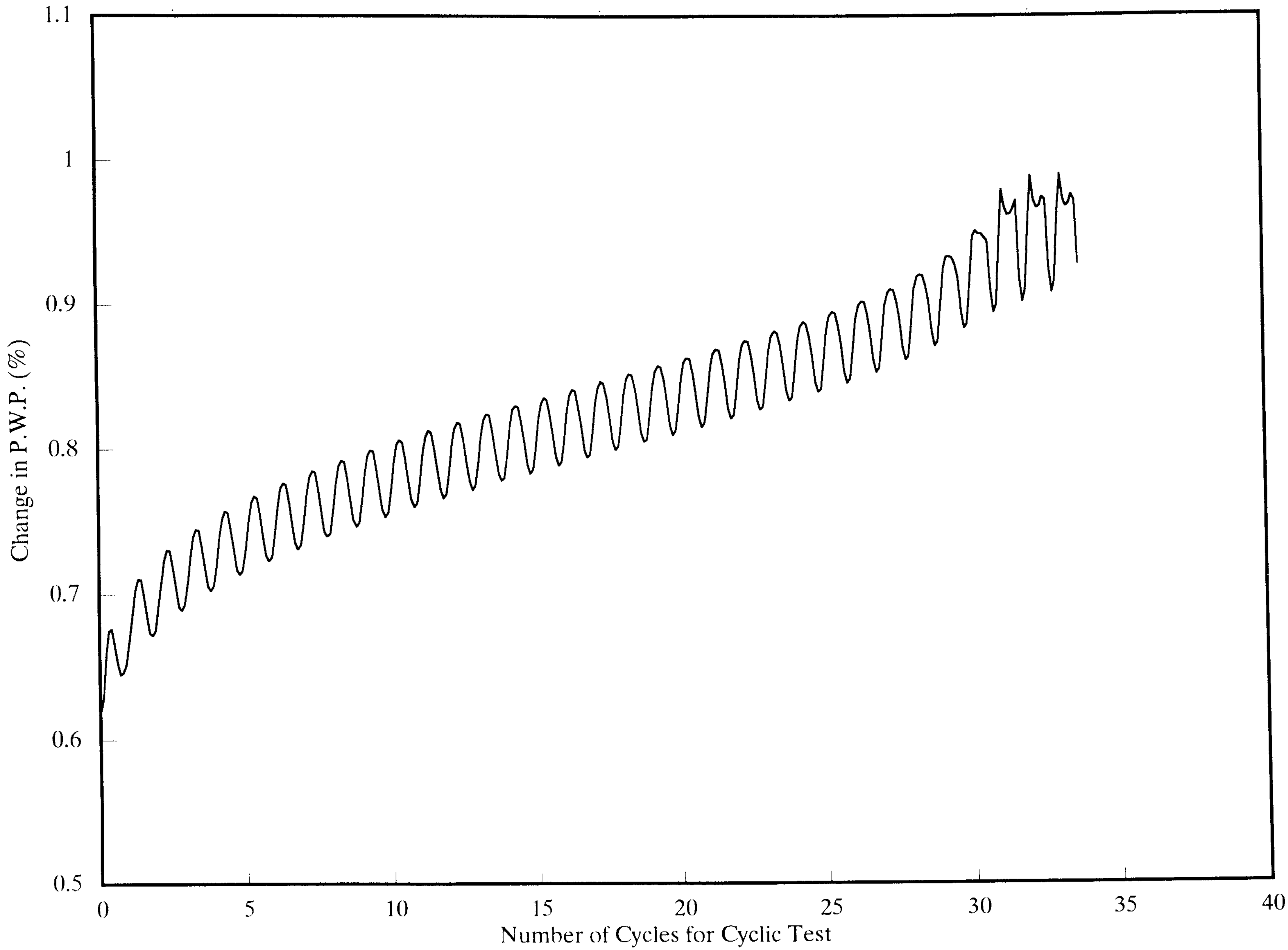
60
40
20
0
-20
-40
-60
Deviator Stress (kpa)
-15
-10
-5
0
5
10
Axial Strain (%)


60
40
20
0
-20
-40
-60
Deviator Stress (kpa)
0
100
200
300
400
500
600
700
800
Elapsed Time (sec.)



Change in Effective Confining Pressure (%)
110
100
90
80
70
60
50
40
30
20
10
0
0
5
10
15
20
25
30
35
40
Number of Cycles for Cyclic Test


300
250
200
150
100
50
0
Effective Confining Stress (kpa)
0
5
10
15
20
25
30
35
40
Number of Cycles for Cyclic Test


1.1
1
0.9
0.8
0.7
0.6
0.5
Change in P.W.P. (%)
0
5
10
15
20
25
30
35
40
Number of Cycles for Cyclic Test